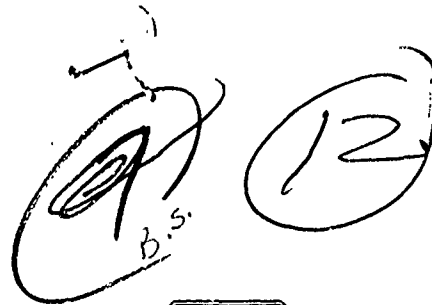


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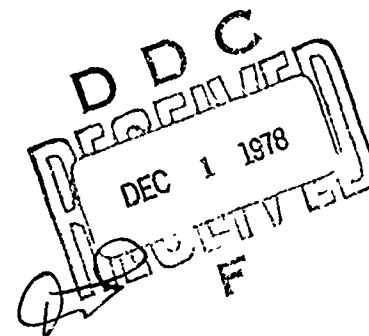
RADC-TR-78-147, Volume I (of two)  
Final Technical Report  
September 1978

PARAMETRIC ANTENNA ANALYSIS SOFTWARE PACKAGE  
Aperture Theory and Design Tables

Robert J. Hancock  
John R. Fricke

Vanderbilt University

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The software described provides a tool for accurate quantitative as well as qualitative aperture antenna analysis. Although intended primarily for far-field pattern analysis of large discrete planar arrays, the package can also be used to model reflector antenna systems and optical systems. Any aperture which can be adequately modeled by an array of up to 1000 x 1000 sample points can be treated via the software package.

The report briefly reviews the theory involved, the parameters available, input and output requirements. Examples to illustrate usage are provided, as is a complete User Manual for the software package.

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## PREFACE

This effort was conducted by Vanderbilt University under the sponsorship of the Rome Air Development Center Post-Doctoral Program for RADC/OCSA. Mr. Don Hildebrand of RADC/OCDR was the task project engineer and provided overall technical direction and guidance.

The RADC Post-Doctoral Program is a cooperative venture between RADC and some sixty-five universities eligible to participate in the program. Syracuse University (Department of Electrical Engineering), Purdue University (School of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering) and State University of New York at Buffalo (Department of Electrical Engineering) act as prime contractor schools with other schools participating via sub-contracts with the prime schools. The U.S. Air Force Academy (Department of Electrical Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the Naval Post Graduate School (Department of Electrical Engineering) also participate in the program.

The Post-Doctoral Program provides an opportunity for faculty at participating universities to spend up to one year full time on exploratory development and problem-solving efforts with the post-doctorals splitting their time between the customer location and their educational institutions. The program is totally customer-funded with current projects being undertaken for Rome Air Development Center (RADC), Space and Missile Systems Organization (SAMSO), Aeronautical Systems Division (ASD), Electronics Systems Division (ESD), Air Force Avionics Laboratory (AFAL), Foreign Technology Division (FTD), Air Force Weapons Laboratory (AFWL),

Armament Development and Test Center (ADTC), Air Force Communications Service (AFCS), Aerospace Defense Command (ADC), Hq USAF, Defense Communications Agency (DCA), Navy, Army, Aerospace Medical Division (AMD), and Federal Aviation Administration (FAA).

Further information about the RADC Post-Doctoral Program can be obtained from Mr. Jacob Scherer, RADC/RBC, Griffiss AFB, NY, 13441, telephone Autovon 587-2543, commercial (315) 330-2543.

The works of numerous authors have provided a great deal of analytical information concerning antenna systems and their farfield radiation patterns. A comprehensive antenna performance analysis package, however, is singularly lacking. At the present time many programs exist that calculate the radiation pattern of particular antenna systems. However, a new set of software is often needed for each antenna that is analyzed. It seems desirable, then, that a software package be developed which will allow the quick and accurate calculation of realistic far-field radiation patterns. This report presents just such a development. The software package described herein is capable of modeling a wide variety of antenna configurations and has been given the name Parametric Antenna Analysis Software which is abbreviated to PAAS in future references. The results from any particular antenna evaluation using PAAS are available quickly and in a form that is easy to interpret. The key goals of this development have been speed, accuracy, and versatility with easily evaluated results.

Via PAAS, the designer is provided with a tool for accurate quantitative as well as qualitative antenna analysis. A set of interactive computer programs or software modules are presented which give the user the necessary means to estimate the antenna pattern from a specified aperture excitation. This work is aimed primarily at the user who requires information regarding the far-field radiation pattern of discrete planar arrays. The principal applications

of discrete planar arrays are sampled dish illumination functions evaluated in a reference plane and electronically scanned phased array antennas.<sup>16</sup>

PAAS contains the software necessary to model the current distribution of an antenna array and compute the complex E-field radiation pattern which corresponds to the modeled distribution. Processing of the radiation pattern data by the user may include plotting or a special purpose processing for a particular user application. In this report the data are plotted for illustrative purposes to show the capabilities of PAAS. The data are plotted in one of two modes. A symbolic representation using alphanumeric characters gives an accurate quantitative look at various aspects of the pattern such as main lobe width and side lobe level. A pseudo three dimensional plot gives qualitative information about the same pattern.

With the software package described in this report, the antenna designer can quickly and accurately determine the far-field radiation patterns for a specific antenna aperture excitation. The speed of this design tool allows the user to quickly change one parameter after another to evaluate the effect on the radiation pattern. The ability to make these evaluations quickly and accurately was considered essential to the success of this software package.

This report has been divided into two volumes. Volume 1 contains: (1) A discussion of the modeling theory used in developing the PAAS modules, (2) appendix 1 which provides a cross reference between the input data and the figures shown in volume 1, and (3) appendices 2 and 3 which contain tables of the Taylor and Bayliss weighting functions. Volume 2 contains appendix 4 (PAAS user manuals) and appendix 5 (PAAS computer program documentation).

## EVALUATION

Contract No. F30602-75-C-0122, Parametric Antenna Analysis Software Package (Vol I: Aperture Theory and Design Tables; Vol II: Computer Program Documentation and User Manuals)

A complete, user-oriented, software package for use in performing parametric analyses of the spatial response of large aperture antennas has been developed under this effort. The package has been installed and tested on RADC's H6180 computer facility. The simulation is capable of modeling a wide variety of antenna configurations with speed and accuracy. It can provide both quantitative and qualitative results, and can model both reflector and array antennas of up to  $1000 \lambda$  extent.

The software package can be used most efficiently by operating it via the Interactive Radar Simulator facilities developed under contract F30602-75-C-0063. However, it has been designed and implemented in such a way that it is also usable from any terminal having access to the Honeywell 6180 GCOS executive. In this usage, the program can be run using the CARDIN subsystem.

It is planned to make extensive use of this software package for studies being conducted under RADC's Spaceborne Radar and Advanced Tactical Radar programs.

The software was developed by personnel at Vanderbilt University under the sponsorship of the RADC Post-Doctoral Program. This effort fits into the RADC Technology Plan under TPO-R1C, Surveillance Sensor Technology, and under TPO R4B, Surveillance ECCM.

*Donald A. Hildebrand*  
DONALD A. HILDEBRAND  
Project Engineer

## TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION . . . . .	1
1.1 Fresnel-Kirchhoff Diffraction Integral . . . . .	1
1.2 Fourier Transform Representation . . . . .	4
1.3 Parametric Antenna Analysis Software (PAAS) General Description . . . . .	5
1.4 Weighting Functions . . . . .	7
1.5 Deterministic Phase Functions . . . . .	9
1.6 Random Phase Errors . . . . .	9
1.7 Statistical or Space Tapered Arrays . . . . .	10
1.8 Special Antenna Options . . . . .	10
1.9 Prospectus . . . . .	11
II. APERTURE TO FAR-FIELD MAPPING, FFT2DX. . . . .	13
2.1 The Relationship Between Terminal Current and the Radiated Field. . . . .	13
2.2 Discrete Fourier Transform . . . . .	15
III. THE ARRAY LOADER, PLARY. . . . .	20
3.1 Introduction . . . . .	20
3.2 Shape and Size . . . . .	21
3.3 Weighting Functions . . . . .	24
3.4 Beam Steering and Phase Quantization . . . . .	51
3.5 Quadratic Phase Error. . . . .	57
3.6 Bessel Phase Error . . . . .	62
3.7 Statistical Loading or Space Tapering. . . . .	62
IV. RANDOM PHASE ERRORS, RNDERR . . . . .	70
V. APERTURE MODIFICATION, FILMOD . . . . .	78

	Page
VI. CONCLUSION . . . . .	87
REFERENCES . . . . .	89
APPENDICES	
1. Figure/Computer Run Cross Reference . . . . .	91
2. Taylor Weighting Function Tables . . . . .	107
3. Bayliss Weighting Function Tables . . . . .	131

# LIST OF FIGURES

Figure	Page
1. Geometry of scalar diffraction field. . . . .	2
2. Block diagram of PAAS modules . . . . .	8
3. A representative antenna element in freespace . . . . .	14
4. Planar grid of discrete radiators and angles to observation point, $P(r, \theta, \phi)$ . . . . .	16
5. Far-field of 40 x 40 rectangular aperture . . . . .	22
6. Far-field of circular aperture w/radius = 32 . . . . .	23
7. Cosine aperture current distribution w/radius = 32 . . . . .	27
8. Far-field of cosine distribution . . . . .	28
9. Far-field of cosine distribution (Plotted using RTI4) . . . . .	29
10. Blackman aperture current distribution . . . . .	31
11. Far-field of Blackman distribution . . . . .	32
12. Kaiser aperture current distribution (Kaiser variable equal to 2) . . . . .	34
13. Far-field of Kaiser distribution (Kaiser variable equal to 2) . . . . .	35
14. Kaiser aperture current distribution (Kaiser variable equal to 8) . . . . .	36
15. Far-field of Kaiser distribution (Kaiser variable equal to 8) . . . . .	37
16. Triangular aperture current distribution . . . . .	38
17. Far-field of triangular distribution . . . . .	39
18. 20 dB Taylor aperture current distribution with $N = 10$ . . . . .	42



Figure	Page
19. Far-field of 20 dB Taylor distribution with $\bar{N} = 10$ . . . . .	43
20. Bessel aperture current distribution. . . . .	45
21. Far-field of Bessel distribution . . . . .	46
22. Cubic aperture current distribution . . . . .	48
23. Far-field of cubic distribution . . . . .	49
24. 20 dB Bayliss aperture current distribution with $\bar{N} = 10$ . . . . .	52
25. Far-field of 20 dB bayliss distribution with $\bar{N} = 10$ . . . . .	53
26. Projection of points on the $\sin \theta$ plane onto the unit hemisphere . . . . .	55
27. Far-field of uniform distribution with orthogonal beam steering angles $(32.0^\circ, 15.0^\circ)$ , $n = 20$ . . . . .	56
28. Far-field of uniform distribution with orthogonal beam steering angles $(22.0^\circ, 15.0^\circ)$ , $n = 3$ . . . . .	58
29. complete visible region in far-field of 70 dB Taylor distribution with $N = 15$ and orthogonal beam steering angles $(22.0^\circ, 15.0^\circ)$ , $n = 3$ . . . . .	59
30. Far-field of uniform distribution with $90.0^\circ$ of quadratic phase error at the edge of the aperture in the x-direction (40 x 40 rectangular aperture) . . . . .	61
31. Far-field of uniform distribution with $90.0^\circ$ of Bessel phase error at the center of the aperture (circular aperture w/radius = 32) . . . . .	63
32. 20 dB statistically thinned Taylor aperture current distribution with $\bar{N} = 10$ . . . . .	66
33. Far-field of statistically thinned Taylor distribution with $\bar{N} = 10$ . . . . .	67
34. Far-field of 30 dB statistically thinned Taylor distribution with $\bar{N} = 3$ , radius = 45, 780 active elements . . . . .	69
35. Far-field of 20 dB Taylor distribution with $\bar{N} = 10$ , and uniform random phase error distribution with a mean of $0.0^\circ$ and a width of $45.0^\circ$ . . . . .	72

Figure	Page
36. Far-field of 70 dB Taylor distribution with $\bar{N} = 15$ and radius = 32. . . . .	72
37. Far-field of 70 dB Taylor distribution with $\bar{N} = 15$ , radius = 32, and a uniform random phase error distribution with a mean of $0.0^\circ$ and a width of $45.0^\circ$ . . . . .	74
38. Far-field of 70 dB Taylor Distribution with $\bar{N} = 15$ , radius = 64, and a uniform random phase error distribution with a mean of $0.0^\circ$ and width of $45.0^\circ$ . . . . .	76
39. Far-field of 70 dB Taylor distribution with $\bar{N} = 15$ , radius = 32, orthogonal beam steering angles ( $21.09^\circ$ , $14.06^\circ$ ), and a uniform random phase error distribution with a mean of $0.0^\circ$ and a width of $45.0^\circ$ . . . . .	77
40. Uniform aperture current distribution with a radius of 32 samples and a J-feed. Feed radius of 4 samples and EM transmission line width of 2 samples . . . . .	79
41. Far-field of uniform distribution with J-feed shown in Figure 40 . . . . .	82
42. Uniform aperture current distribution in shape of J-feed that was removed from the distribution in Figure 40 . . . . .	83
43. Far-field of uniform distribution in shape of J-feed shown in Figure 42 . . . . .	84
44. Far-field of triangular distribution with J-feed. . . . .	85

## CHAPTER I

### INTRODUCTION

#### 1.1 Fresnel-Kirchhoff Diffraction Integral

Following Skolnik's work, the Fresnel-Kirchhoff scalar diffraction integral expressed in Equation 1.1 defines the relationship between a radiating source and the E-field distribution in space caused by that source (1).

$$F(P) = \frac{1}{4\pi} \int_{\text{area}} G(\xi, \eta) \exp(-jkr) \left[ \left( jk + \frac{1}{r} \right) \cos(n, r) + jk \cos(n, s) \right] \frac{1}{r} d\xi d\eta \quad (1.1)$$

where:  $F(P)$  = The scalar field to a point  $P(x, y, z)$

$G(\xi, \eta)$  = The aperture excitation function

$(n, r)$  = The angle between the normal to the aperture face and the "r" direction.

$(n, s)$  = The angle between the normal to the aperture face and the phase illumination across the aperture.

$r$  = Distance from the point  $P(x, y, z)$  to the incremental element area  $d\xi d\eta$

$k$  =  $2\pi/\lambda$

The relationship between these parameters is illustrated in Figure 1. A better understanding and a derivation of this integral may be seen in Marion and Silver (2,3). Silver and Skolnik both stress the heuristic nature of the Kirchhoff integral. Skolnik quotes from Barakat, "The theoreticians believe in the Kirchhoff theory because

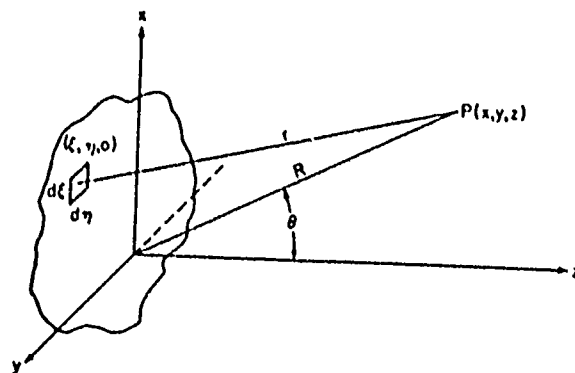


Figure 1: Geometry of scalar diffraction field.

they hold it to be an experimental fact, while the experimentalists think it to be a mathematical theorem (4)." The integral, even though it lacks mathematical rigor however, does characterize the complex E-field distribution of a radiating source and is used as the basic definition of the radiation pattern throughout this work.

There are three "regions" of interest which are characterized by special approximations to the diffraction integral. The first two regions in radiated space are the near-field and the Fresnel region. All of the approximations used for these also apply to the third region, the far-field, which is the subject of this paper.

Skolnik has shown that the Kirchhoff integral is simplified to the integral shown in Equation 1.2 for the far-field approximations.

$$F(P) = \frac{1}{\lambda R} \exp\{-jkR\} \int_{\text{area}} G(\xi, \eta) \exp\{jk \sin \theta (\xi \cos \Psi + \eta \sin \Psi)\} d\xi d\eta \quad (1.2)$$

where:  $R$  = The distance from the origin to the point  $P(x, y, z)$

$k$  =  $2\pi/\lambda$

$\xi, \eta$  = Incremental coordinates in the x-y plane

$\theta$  = Angle of elevation

$\psi$  = Angle of azimuth

For a rectangular aperture with dimensions  $a \times b$  and uniform amplitude and phase excitation the integral is separable and gives (assuming  $G(\xi, \eta) = 1$ ) Equation 1.3.

$$F(\theta, \psi) = \frac{jE_0}{\lambda R} \exp[-jkR] \int_{-a/2}^{a/2} \exp(jk\xi \sin\theta \cos\psi) d\xi \cdot \int_{-b/2}^{b/2} \exp(jk\eta \sin\theta \sin\psi) d\eta \quad (1.3)$$

Integrating Equation 1.3 results in Equation 1.4.

$$F(\theta, \psi) = \frac{\sin[(\pi a/\lambda) \sin\theta \cos\psi]}{(\pi a/\lambda) \sin\theta \cos\psi} \cdot \frac{\sin[(\pi b/\lambda) \sin\theta \sin\psi]}{(\pi b/\lambda) \sin\theta \sin\psi} \quad (1.4)$$

The terms outside the integral in Equation 1.3 have been dropped since they only have a scaling effect on  $F(\theta, \psi)$ . It can be seen that Equation 1.4 is the product of two  $(\sin x)/x$  functions which characterizes the far-field radiation effects of a rectangular aperture.

For the evaluation of a circular aperture a change of variables to polar coordinates and appropriate substitution in Equation 1.2 gives the circularly symmetric equivalent of Equation 1.3

$$F(u) = 2\pi a^2 \int_0^1 G(r) J_0(ur) r dr, \quad (1.5)$$

where  $u = \sin\theta$ , "a" is the radius of the aperture, and  $J_0$  is the Bessel function of the first kind and order zero. For  $G(r) = 1$  the far-field becomes

$$F(u) = 2\pi a^2 \frac{J_1(u)}{u}. \quad (1.6)$$

## 1.2 Fourier Transform Representation

The integral representation of the far-field radiation pattern of a continuous aperture excitation given in Equation 1.2 is in general very difficult to evaluate. In the case of the rectangular aperture the relationship between the aperture excitation and the far-field radiation pattern can be shown to be the product of two Fourier Transforms.

For the  $\psi = 0$  plane and with a substitution of  $u = \pi a(\sin\theta)/\lambda$  and  $x = (2/a)\xi$  into Equation 1.3 the far-field radiation pattern becomes

$$F(u) = \int_{-1}^1 G(x) e^{jux} dx. \quad (1.7)$$

This equation is a finite Fourier transform of the illumination function.

For most continuous aperture excitations, however, the integral in Equation 1.2 is not so easily evaluated. To show that the far-field radiation pattern of a circular aperture is the Fourier transform of the aperture excitation requires a knowledge of the relationships between Hankel and Fourier transforms. Other aperture excitations

and shapes become completely intractable.

In Chapter II a discussion of the relationship between discrete planar excitations and their corresponding far-field radiation patterns is presented. It is shown that for all discrete planar excitations with equally spaced radiators, the far-field pattern is a 2 dimensional DFT of the aperture excitation.

### 1.3 Parametric Antenna Analysis Software (PAAS) General Description

The PAAS modules presented in this report consist of a set of Fortran modules used to load and transform a desired antenna design. The modules are broken down into three groups: 1) loading modules, 2) support modules, and 3) transform module. All of the software was developed for use on a Honeywell 6000 series computer using the time-sharing GCOS operating system (5).

The aperture loading software includes:

- 1) PLARY The initial aperture loader. PLARY includes many weighting and deterministic phase functions and has provisions for both amplitude and space tapered arrays of rectangular, circular, and elliptical shape.
- 2) RNDERR Modifies a previously generated aperture by adding random phase errors of specified distribution (uniform or Gaussian), mean, and standard deviation.
- 3) FILMOD Modifies a previously generated aperture by "punching holes" and/or changing individual antenna

element values according to user specified instructions.

The support software includes:

- 1) TBL5      A program to generate numerical tables of various weighting functions. The user provides radius (or length), type, and other appropriate weighting parameters. The Program also generates tables to compare to data generated by the probability density estimator program PDFESTR.
- 2) PDFESTR   A program used to generate the probability density histogram of statistically loaded or space tapered apertures.
- 3) RTI4(6)   A symbolic display module which converts relative magnitude into letters of the alphabet, numerals, or punctuation symbols and arranges them into a matrix which is printed on the time-sharing terminal. The program allows the user to vary the reference magnitude and the magnitude increment between symbols so that a very large dynamic range may be displayed.
- 4) PLTDVR    PLTDVR formats and transfers data to a recording device in a form that is used in producing a pseudo-3D representation on a 4014 Tektronix graphics display terminal.

The Fortran batch program used for mapping the antenna aperture excitation into the far-field radiation pattern is FFT2DX. The program



selects an aperture distribution and performs a two-dimensional Fourier transform on the input array to generate the corresponding far-field.

In summary, PAAS is a group of modules which allow the designer to model an antenna of arbitrary characteristics. In the following chapters the capabilities of PAAS are illustrated.

The block diagram in Figure 2 depicts how the various PAAS modules fit together. The user interacts with all of the time-sharing system (TSS) modules (except PLTDVR) through a standard time sharing terminal. The data that is formatted and transmitted by PLTDVR must be recorded by the user on a data storage device. The recording and all the plots were made using the Dedicated User Interface Subsystem (DUIS) (6). From the block diagram it can be seen how one would progress through an antenna simulation. Details of the modules, how to use them, documentation, etc. are presented in the appendices.

#### 1.4 Weighting Functions

Weighting functions are used to modify the effects of the Gibbs phenomenon which occur as a result of transforming a truncated sequence (7). The ratio of the sidelobe amplitude to the mainlobe amplitude is decreased at the expense of broadening the main beam when amplitude weighting is used.

Some weighting functions, notably the Taylor, produce extremely good results (8-10). The Taylor may be used to approach the ideal weighting distribution, Dolph-Chebyshev, to any degree of accuracy that the designer wishes (11).

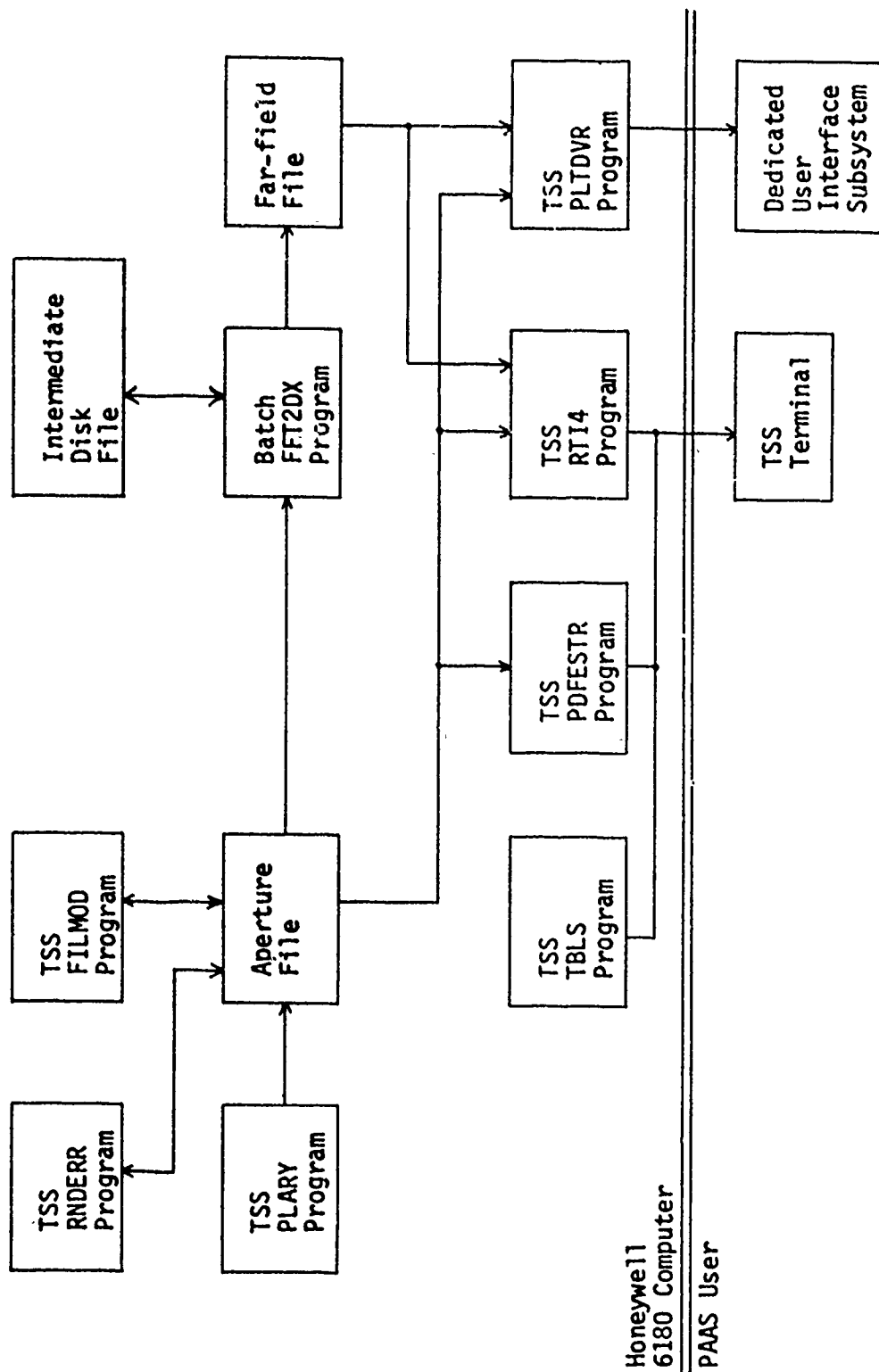


Figure 2: Block diagram of PAAS modules

Some of the weighting functions are for specific aperture shapes. There are eight weighting functions implemented in the array loader PLARY. The element weights for the rectangular and elliptical arrays are calculated as the product of two orthogonal weighting functions evaluated at each element with respect to the center of the array. The element weights for the circular arrays are evaluated using a circularly symmetric weighting function.

### 1.5 Deterministic Phase Functions

The three deterministic phase functions which are included in the simulation are linear phase shift, quadratic phase error, and a Bessel phase error distribution (1,12,13). The linear phase shift is implemented for beam steering purposes. Quadratic phase error is introduced by bending in mechanical antenna structures. The Bessel phase error distribution results from machining errors in circular mechanical dish antennas (12).

### 1.6 Random Phase Errors

In addition to the deterministic phase functions discussed above the program RNDERR allows the user to add random phase errors to the aperture current distribution. Phase errors of this nature have been discussed by many authors (13-19). Random phase errors are present in any antenna system. They arise as a result of a number of physical causes such as uneven transmission line length, non planar apertures and variable transmitter outputs. Sidelobe deterioration and loss of main beam gain are the major effects of random phase errors.

### 1.7 Statistical or Space Tapered Arrays

In realistic design situations the antenna designer must be concerned with space tapered or thinned arrays because of the economics of building large phased array antennas (20). Statistical tapering is achieved by loading the antenna array elements according to a probability density function. The density function is determined by the normalized values of the design weighting function. The elements that are active radiate unit power and those that are not active are replaced by dummy elements. This leads to an antenna system with fewer active radiators and all radiating at one power level. These antenna designs are useful economically but can create difficulties because of sidelobe level deterioration.

### 1.8 Special Antenna Options

The illumination function of most mechanical dish antennas are blocked by feeds, supports, or other similar structures which cause deterioration of the far-field radiation pattern. This can be simulated using the special module, FILMOD. FILMOD is used to "punch holes" and/or change individual element values in the input aperture distribution. Another problem in phased array antennas is the possibility of losing individual elements due to random failures. Worse still, power to entire subarrays may be lost. This causes a hole in the aperture distribution but is usually rather irregularly shaped so that its effect is minimized. This can be modeled by going through the aperture array and zeroing out the individual

elements that would be lost in a transmitter failure.

### 1.9 Prospectus

The set of PAAS modules presented here are used to model a wide variety of antenna situations. The far-field radiation patterns are computed using the module FFT2DX. The designer is given many options in both phased-array antennas and also in mechanical dish antennas. In situations where a closed form solution of a particular antenna design is not known (which is realistically the case for all antenna designs) the designer may use the analysis package described in this thesis to investigate the far-field radiation pattern. The designer may also run sensitivity tests of the antenna to various effects such as random phase errors, subarray or element loss, and beam steering. The work of the designer is greatly aided, and he may now see in both a quantitative as well as in a qualitative way the results of a particular antenna design.

In the text that follows, Chapter II through V, illustrative material is presented that indicates to the reader what situations the simulation is capable of modeling. Chapter II discusses in detail the relationship between a discrete planar aperture excitation and the far-field radiation pattern caused by the excitation. Chapter III discusses the planar array loader and all the capabilities included in the loader. Chapter IV discussed the far-field effects of random phase errors. Chapter V discusses the simulation of aperture radiation blockage and its effect on the far-field radiation pattern.

The appendices are included to instruct the reader on how to use the simulation. The computer software, documentation, and flow charts for all the simulation programs are presented. The documentation includes a discussion of the meaning of the input variables, theory of operation for the program, and the subroutines required by the program. Detailed listings are presented so that the user may better understand the logic of the program and/or modify the program to suit his particular needs.

## CHAPTER II

### APERTURE TO FAR-FIELD MAPPING, FFT2DX

#### 2.1 The Relationship Between Terminal Current and the Radiated Field

An aperture is defined herein as an array or grid of radiating elements. The elements are assumed to be isotropic radiators and are equally spaced along the vertical and the horizontal axes. From M. T. Ma the E-field produced by a radiator is defined by the following equation (21).

$$E_i(\theta, \psi) = \beta(\theta, \psi) I_i \exp\{j(2\pi/\lambda) r_i \cos \psi_i + \alpha_i\} \quad (2.1a)$$

$$= \beta(\theta, \psi) I_i e^{jC_i} \quad (2.1b)$$

where

$$C_i = (2\pi/\lambda) r_i \cos \psi_i + \alpha_i \quad (2.2)$$

- $I_i$  = The magnitude of the current in the radiating element
- $\alpha_i$  = The phase component of the radiating element
- $\psi_i$  = The angle between the radiating element and the observation point
- $r_i$  = Radius from the origin to the radiating element
- $\beta(\theta, \psi)$  = Function relating terminal current in the elemental radiator to the E-field at some radius, R, for the angles  $\theta$  and  $\psi$ .

The relationship between these parameters may be seen more clearly in Figure 3. The E-field and thus the power field are related to

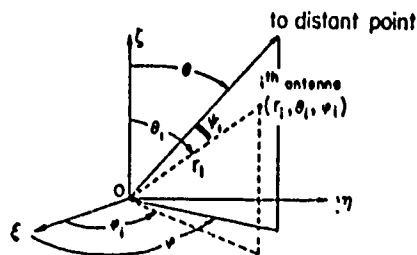


Figure 3. A representative antenna element in the freespace.

the radiator current by a constant,  $\beta(\theta, \psi)$ , at each point in the far-field. As a result of this it is now appropriate to describe the aperture element excitation in terms of a complex aperture current distribution.

The E-field distribution,  $E_i(\theta, \psi)$ , in the far-field caused by each radiator has been shown to be related to the terminal current,  $\beta(\theta, \psi) \cdot I_i$ , times a constant,  $\exp(jC_i)$ . The E-field distribution of all the radiators,  $E(\theta, \psi)$ , is the sum of the E-fields from each radiator (9). Thus,

$$E(\theta, \psi) = \sum_i E_i(\theta, \psi) \quad (2.3)$$

$$= \sum_i \beta(\theta, \psi) I_i e^{jC_i} \quad (2.4)$$

$$= \underbrace{\beta(\theta, \psi) I_{\max}}_{\text{elemental radiator pattern}} \underbrace{\sum_i W_i e^{jC_i}}_{\text{array factor}} \quad (2.5)$$

where:  $I_i = I_{\max} W_i$  and  $0 \leq W_i \leq 1$ .



When the radiation pattern is expressed in the form of Equation 2.5 it is seen to be the product of two terms. The first is a function of the element characteristics, has the units of volts, and is called the elemental radiator pattern. The second term is a dimensionless quantity that is a function of the array shape and configuration. This term is called the array factor. Since isotropic radiators have been assumed,  $\beta(0, \psi)$  is a constant and thus the elemental radiator pattern is a constant. The radiator pattern that is computed then is equal to the array factor times a scaling constant. To evaluate the radiation pattern of an array of identical non-isotropic radiators the computed far-field must be multiplied by the function  $\beta_n(0, \psi)$  where  $n$  denotes the particular type of non-isotropic radiator used and  $\beta_n(0, \psi)$  is the function relating terminal current to far-field voltage for the selected elemental type.

## 2.2 Discrete Fourier Transform

Now that the relationship between current and the radiation from a particular element has been established, the current to each element may be used to express the aperture excitation. In Figure 4, a grid of equally spaced elements is shown along with the angles to the far-field observation point,  $P(r, \theta, \phi)$ . The E-field radiation in the far-field is given by (22)

$$E(\theta, \phi) = \beta(0, \phi) \sum_{m=-N_x}^{N_x} \sum_{n=-N_y}^{N_y} I_{mn} \exp\{jksin\theta(nd_x \cos\phi + nd_y \sin\phi)\} \quad (2.6)$$

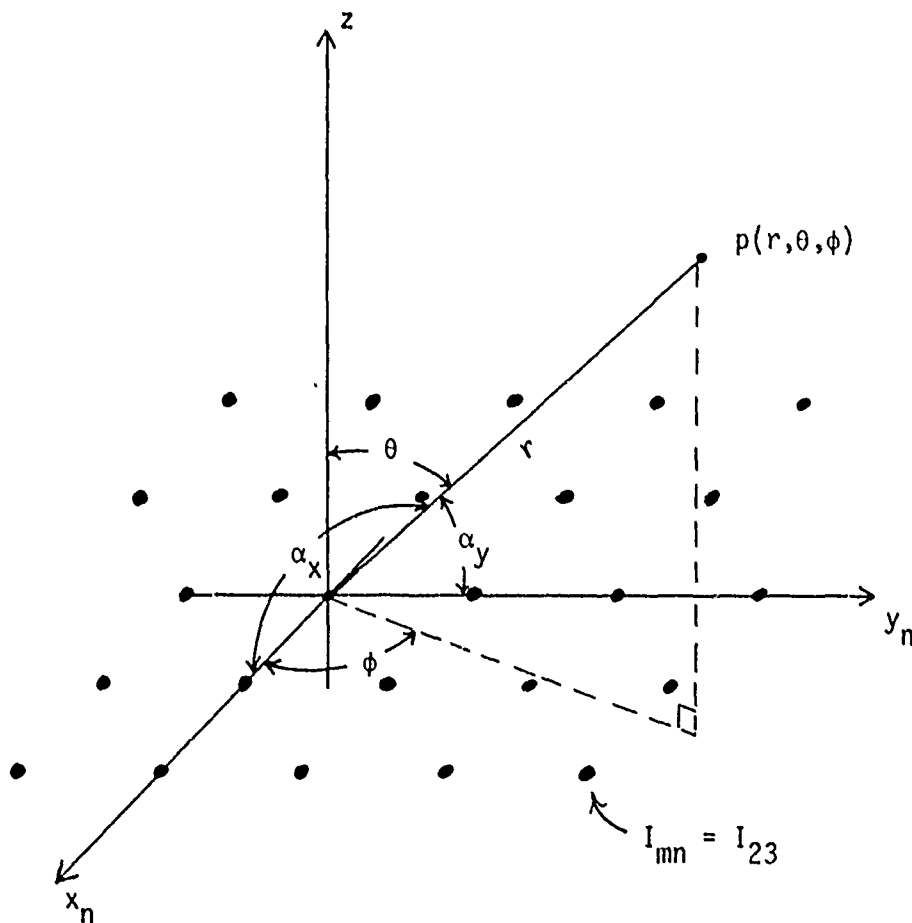


Figure 4. Planar grid of discrete radiators and angles to observation point,  $P(r, \theta, \phi)$ .

This equation may be rewritten as

$$E(\theta, \phi) = \beta(\theta, \phi) \sum_{m=-N_x}^{N_x} \exp(jk \sin \theta \cos \phi) \cdot \sum_{n=-N_y}^{N_y} I_{mn} \exp(jk \sin \theta \sin \phi) \quad (2.7)$$

Equation 2.7 is in a form that has isolated the x and y components. The parameters  $\theta$  and  $\phi$  are however still involved in both summations. It would be convenient if the two summations could be carried out in rectangular coordinates rather than polar coordinates. The reasoning

for this becomes evident later.

From Figure 6 the relationship between the angles  $\theta$  and  $\phi$  and the angle  $\alpha_x$  and  $\alpha_y$  is seen to be

$$\cos\alpha_y = \sin\theta\sin\phi \quad (2.8a)$$

$$\cos\alpha_x = \sin\theta\cos\phi \quad (2.8b)$$

These are the direction cosines of the vector with azimuth angle,  $\phi$ , and elevation angle,  $\theta$ . Any point in the far-field can be represented by a pair of direction cosines. Now if the direction cosines are substituted into Equation 2.7 it becomes

$$\hat{E}(\cos\alpha_x, \cos\alpha_y) = \beta(\cos\alpha_x, \cos\alpha_y) \sum_{m=-N_x}^{N_x} \exp(jkmd_x \cos\alpha_x) \cdot \sum_{n=-N_y}^{N_y} I_m(n) \exp(jknd_y \cos\alpha_y) \quad (2.9)$$

The polar function  $E(\theta, \phi)$  has been changed to a rectangular function,  $\hat{E}(\cos\alpha_x, \cos\alpha_y)$ . The relationship from the points in space to the aperture plane are now determined by the direction cosine coordinates rather than the angles of azimuth and elevation. The current distribution,  $I_m(n)$ , still represents the original grid of elements. The subscripts have been changed however to represent  $m$  rows of elements with  $n$  elements in each row or a total of  $n$  columns. This is done so that the evaluation of  $\hat{E}$  may be separated into a summation on the rows, then a summation on the columns.

By letting

$$\frac{r_1}{2N_y} = \frac{d_y \cos \alpha_y}{\lambda} \quad (2.10a)$$

and

$$\frac{r_2}{2N_x} = \frac{d_x \cos \alpha_x}{\lambda}$$

Equation 2.9 becomes

$$\begin{aligned} \tilde{E}(r_2, r_1) = \beta(r_2, r_1) & \sum_{m=-N_x}^{N_x} \exp(j \frac{2\pi}{2N_x} r_2 m) \cdot \\ & \sum_{n=-N_y}^{N_y} I_m(n) \exp(j \frac{2\pi}{2N_y} r_1 n) \end{aligned} \quad (2.11)$$

Because of the periodicity of the input function, the limits of the summations may be changed as in the following equation.

$$\tilde{E}(r_2, r_1) = \beta(r_2, r_1) \sum_{m=0}^{N_{xx}} e^{j \frac{2\pi}{N_{xx}} r_2 m} \sum_{n=0}^{N_{yy}} I_m(n) e^{j \frac{2\pi}{N_{yy}} r_1 n} \quad (2.12)$$

where:

$$N_{xx} = 2N_x$$

$$N_{yy} = 2N_y$$

Comparing Equation 2.12 with the Equation for the inverse discrete Fourier transform (IDFT),

$$x(r) = \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} kr} \quad (2.13)$$

it is seen that Equation 2.12 is a two-dimensional IDFT. The far-field of an input aperture can thus be calculated using the FFT algorithm.

The structure of the summations now allows the  $m$  rows of the current distribution to be transformed and then the  $n$  columns. Using

this technique any aperture current distribution can be transformed by doing an FFT across each row and then down each column. This technique is completely general.

The program FFT2DX maps the aperture current distribution into the far-field radiation pattern. The program computes the radiation pattern by doing two sets FFTs. First the rows of the input aperture are transformed and stored onto an intermediate file. The program then transforms the columns of the intermediate data. Only those parts of the far-field requested are stored onto the user designated permanent disk file. The resulting data is the complex E-field pattern of the input planar aperture current distribution.

In the following chapters the input aperture current distributions are discussed and their corresponding far-field radiation patterns are shown. In this way the effects of each aperture feature on the far-field radiation are presented and can be studied along with the specific aperture distribution.

## CHAPTER III

### THE ARRAY LOADER, PLARY

#### 3.1 Introduction

The array loader, PLARY, contains the necessary optional features to load an antenna array. The features included are 1) shape and size, 2) weighting, 3) beam steering (including quantization phase error), 4) Bessel phase error, and 5) statistical loading or space tapering. In the following sections equations and examples for the various features are given. For each feature the far-field is also shown and discussed. Where possible, comparisons to known far-field solutions are made to show the validity of the simulation. Using the aperture to far-field mapping discussed in Chapter II it is shown that the simulation gives expected results for the more complicated antenna apertures. In fact, the work in Chapter II has shown that all the far-field results from the simulation are exact for the given antenna aperture current distribution.

Unless noted otherwise, the aperture plots are current magnitude representations of 64 x 64 element arrays. This allows a radius of 32.0 for circular apertures. The rectangular apertures can, of course, fill the aperture field. In Chapter II it was shown that the far-field radiation pattern of the aperture current distribution is in general a two-dimensional Fourier transform of the aperture distribution. Unless noted otherwise, the dimensions of the computed

far-field are 256 x 256 points. The far-field plots shown are linear energy magnitude plots with dimensions of 64 x 64 points and are located in the middle of the far-field. The plots thus represent 1/16 of the total area of the calculated far-field.

### 3.2 Shape and Size

In Chapter I it is shown in Equation 1.4 that a rectangular aperture produces a far-field radiation pattern that is the product of two  $(\sin P)/P$  functions. Figure 5 illustrates the antenna pattern for an array that has 40 elements on a side and a uniform current distribution. The peak sidelobe level is 13 dB down from the main lobe as is expected. It can also be seen in the figure that the two cardinal planes contain the specified  $(\sin P)/P$  functions and the other points in the far-field are determined by the product of these two orthogonal functions. In Figure 5 the vertical axis is magnitude. The x and y axes are direction cosines defined by

$$y = \cos \alpha_y = \sin \theta \sin \phi$$

and

$$x = \cos \alpha_x = \sin \theta \cos \phi$$

where  $\theta$  is the elevation angle and  $\phi$  is the azimuth angle. These units for each axis are direction cosines and apply throughout the thesis in the far-field radiation plots.

Equation 1.6 defines the far-field radiation pattern of a circular aperture. The expected peak sidelobe level is 17 dB down from the main lobe. Figure 6 illustrates the far-field antenna pattern of a circular aperture with a radius of 32 elements and a uniform current distribution.

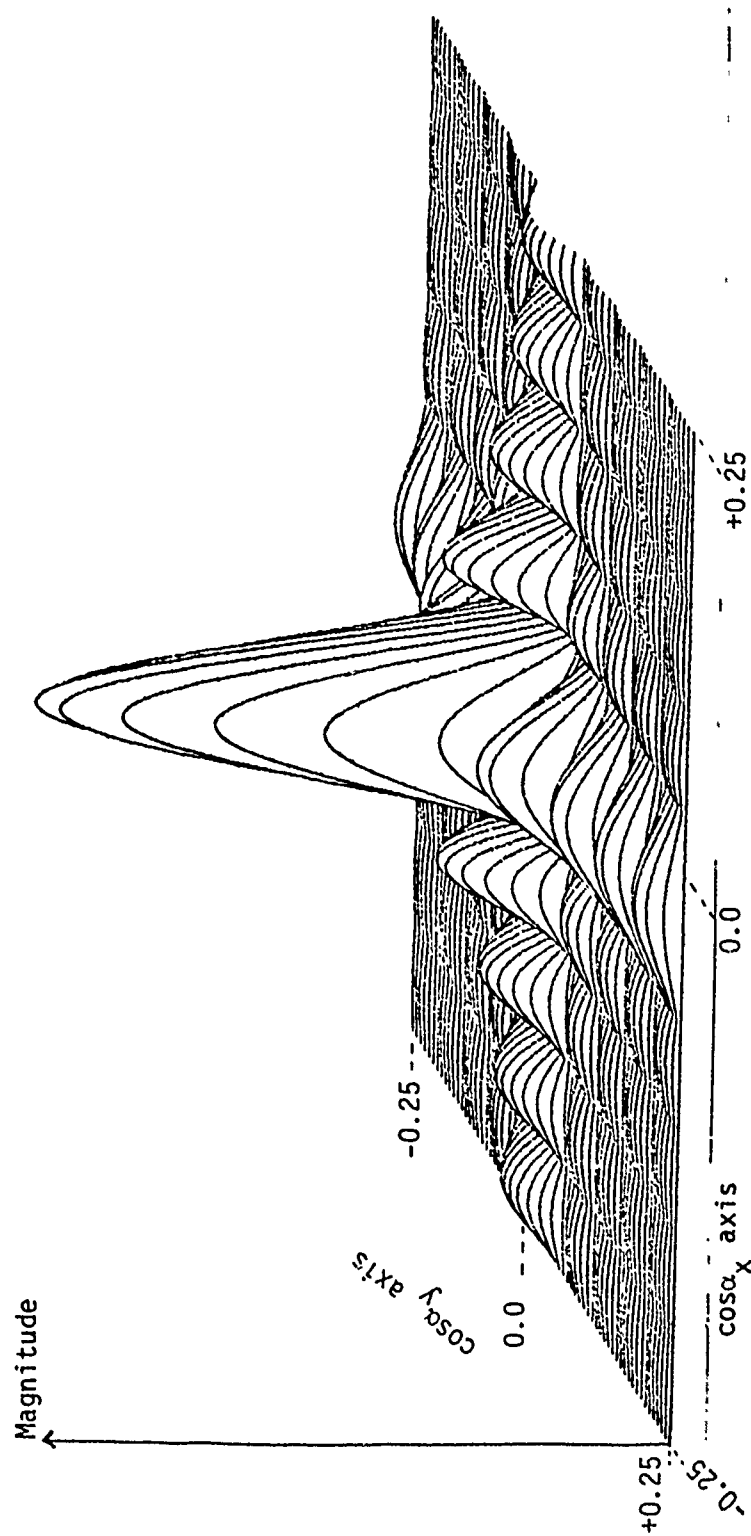


Figure 5. Far-field of 40 x 40 rectangular aperture.



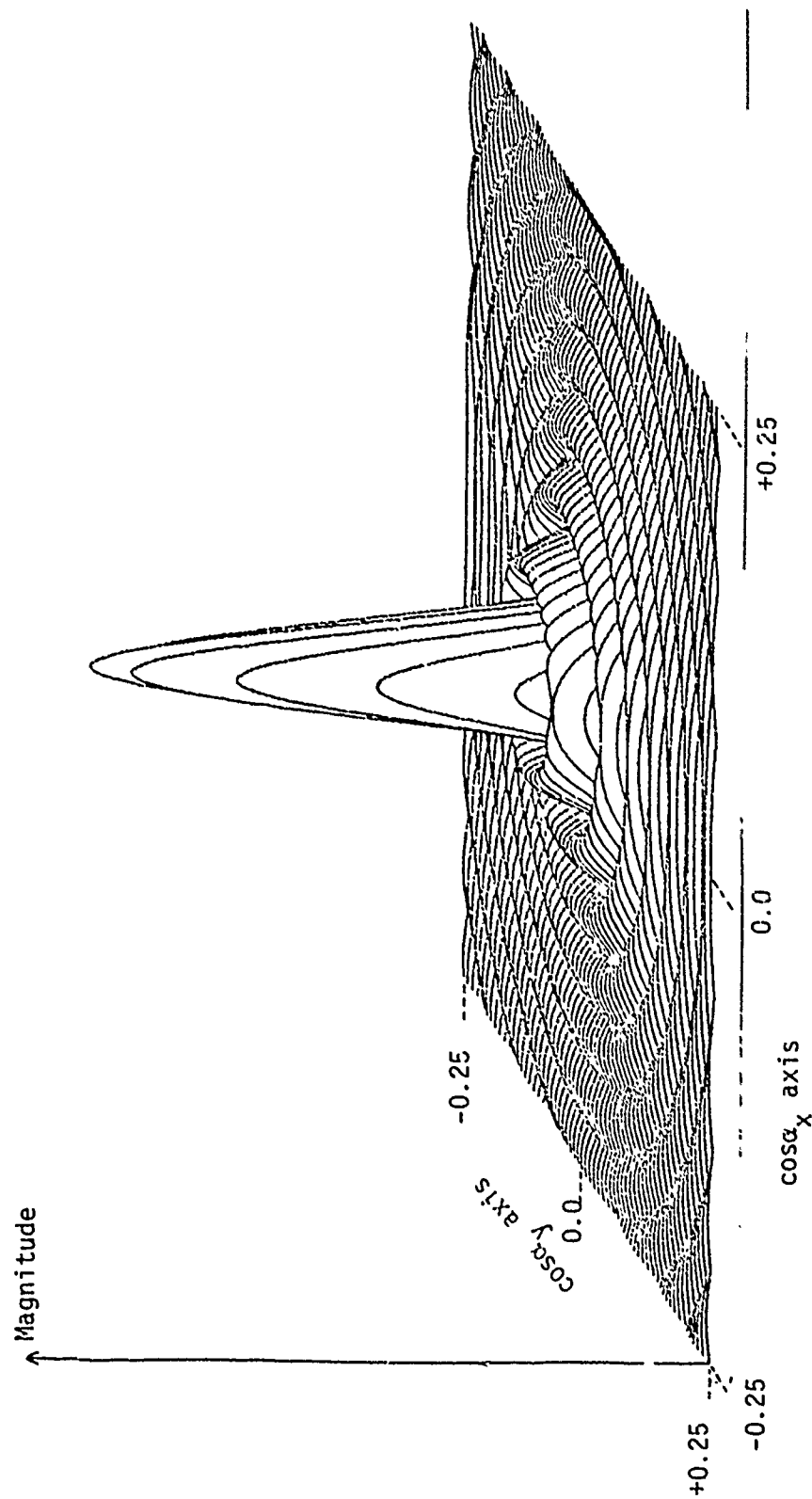


Figure 6. Far-field of circular aperture w/radius = 32.

The peak sidelobe of this plot is 17 dB as expected. The character of the sidelobe structure follows the predicted Bessel function exactly.

Thus, rectangular apertures produce far-field radiation patterns that are characterized by the product of two orthogonal  $(\sin P)/P$  functions. Circular apertures produce far-field radiation patterns that are characterized by a circularly symmetric Bessel function of the first kind and first order. These characteristics are still evident as the underlying nature of the far-field patterns produced by the modified rectangular or circular apertures in the sections to follow.

The size or number of radiating elements,  $N$ , of an antenna determine several antenna radiation characteristics. The beamwidth is effected by the number of elements in the array. As the number of elements increases along one axis the beamwidth decreases along the same axis. Thus if a square aperture were elongated in the  $x$ -direction, the beamwidth in that direction would decrease. The average sidelobe level caused by random errors also decreases as the number of radiating elements increases. A more detailed discussion of random errors is presented in Chapter IV.

### 3.3 Weighting Functions

Weighting functions are used to help improve the main lobe to sidelobe amplitude ratio of the antenna pattern. The pattern shown in Figure 6 is that of a rectangularly weighted circular aperture. This means that there is a uniform current distribution to all the

radiating elements in the aperture grid. The "weighting" produces a rather narrow beam but has sidelobes that are only -17 dB with respect to the main lobe peak. This result is a manifestation of the Gibbs phenomenon which describes the effects of transforming a truncated infinite sequence (7). If the sequence is tapered rather than simply truncated, a compromise is made and the effects of the Gibbs phenomenon are modified. The peak sidelobes are lowered but the narrow beam must be sacrificed for a broader one. There are many types of amplitude tapers or weightings. The weighting functions implemented in the array loader, PLARY, are

- 1) cosine on a pedestal to a power,
- 2) Blackman,
- 3) Kaiser,
- 4) Bartlett or triangular,
- 5) Taylor,
- 6) Bessel,
- 7) cubic, and
- 8) Bayliss.

These functions are discussed below, and examples of both the weighting function and the far-field are shown. A program to calculate the numerical value of these weighting functions is presented in Volume II.

Cosine on a pedestal to a power represents a large group of weighting functions. Both the Hanning and the Hamming weighting functions are special cases of this weighting function. The general

equation for this group of functions is (23)

$$w(x) = P + (1-P) \cdot \cos^N(x\pi/2R) \quad (3.1)$$

where:

- P = Height of the pedestal
- x = Independent variable
- R = Radius or half-span of the weighting function
- N = Power of the cosine function

A common weighting is one half cycle of a cosine function ( $P = 0.0$ ) with the zero crossings at the edge of the aperture (23). This weighting gives 26 dB sidelobes. An example of the weighting function is shown in Figure 7 while the corresponding far-field is shown in Figure 8. It is not possible to determine the sidelobe level of the far-field from the 3D-plot in Figure 8, but using another representation, RTI4, the sidelobe level may be accurately determined. An example of this representation is seen in Figure 9 when the spacing between letters is 2 dB. The peak of the far-field gain is 62 dB and is represented by an "A" on the plot. The first sidelobe is 26 dB below the main lobe and is represented by an "N" on the plot. The peak and the first two sidelobes are indicated in Figure 9 by the outlined areas. Using this representation the sidelobe level of the far-field can be determined within the accuracy of the letter spacing. The sidelobe levels given throughout the rest of this text were determined using plots of the type shown in Figure 9. Most of the plots used for illustration however are the type shown in Figures 7 and 8 because of their overall qualitative information content.

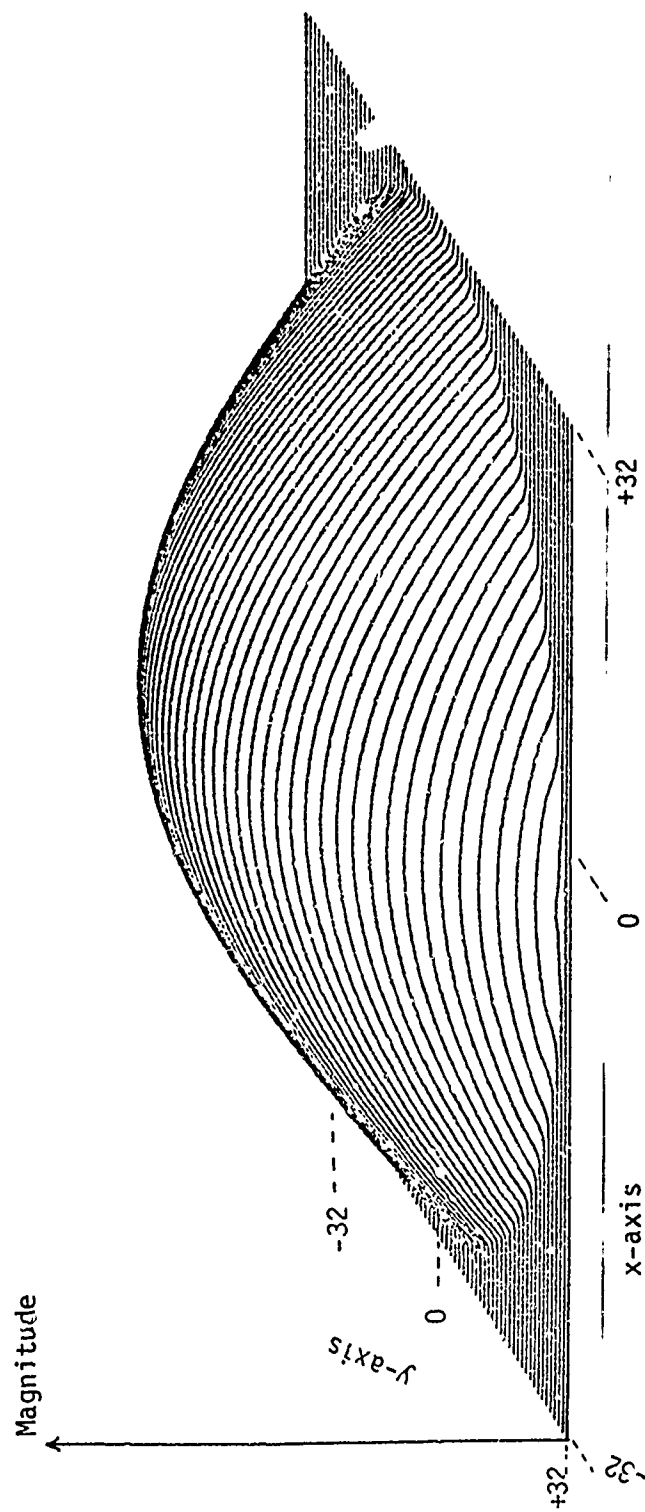


Figure 7. Cosine aperture current distribution w/radius = 32.

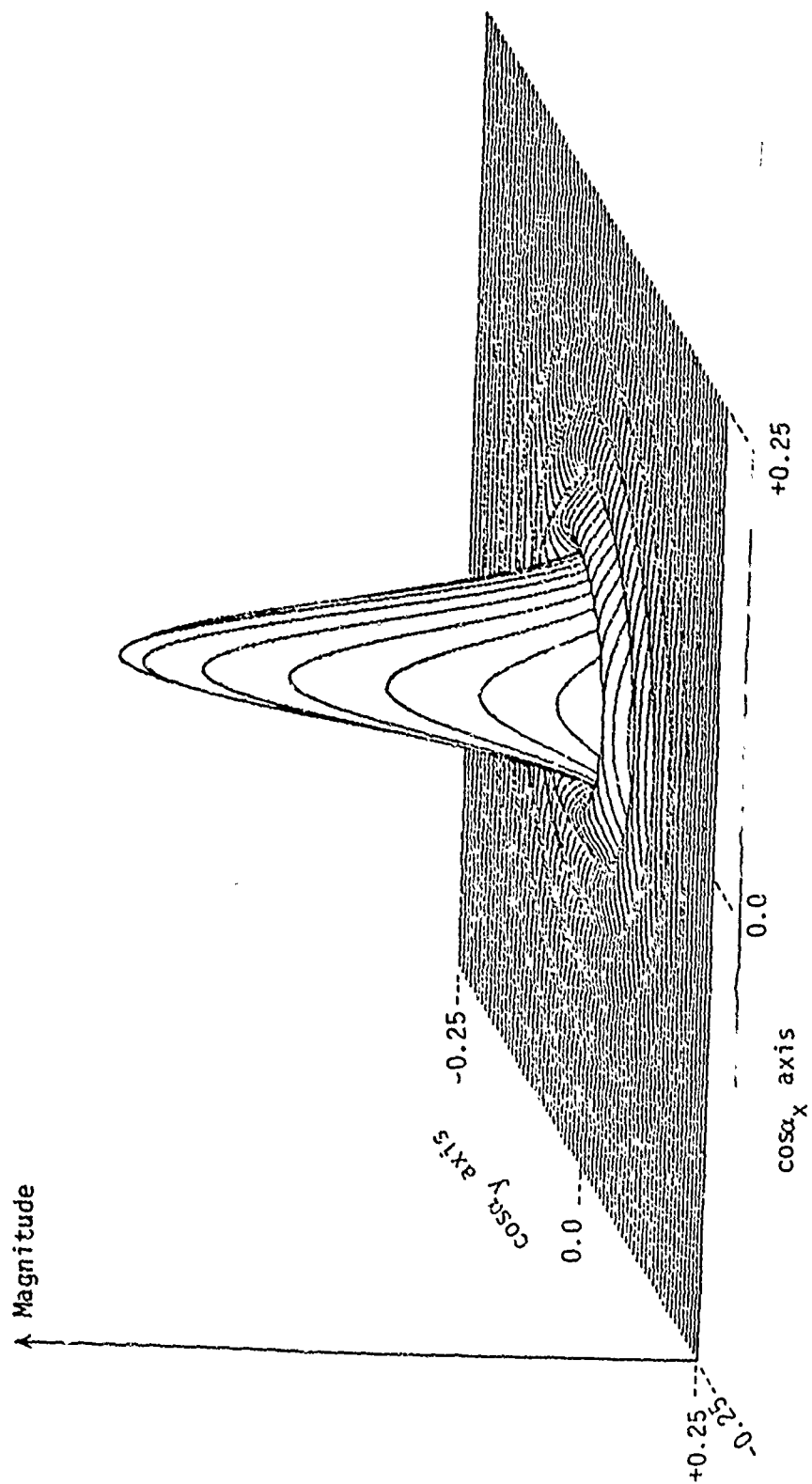


Figure 8. Far-field of cosine distribution.

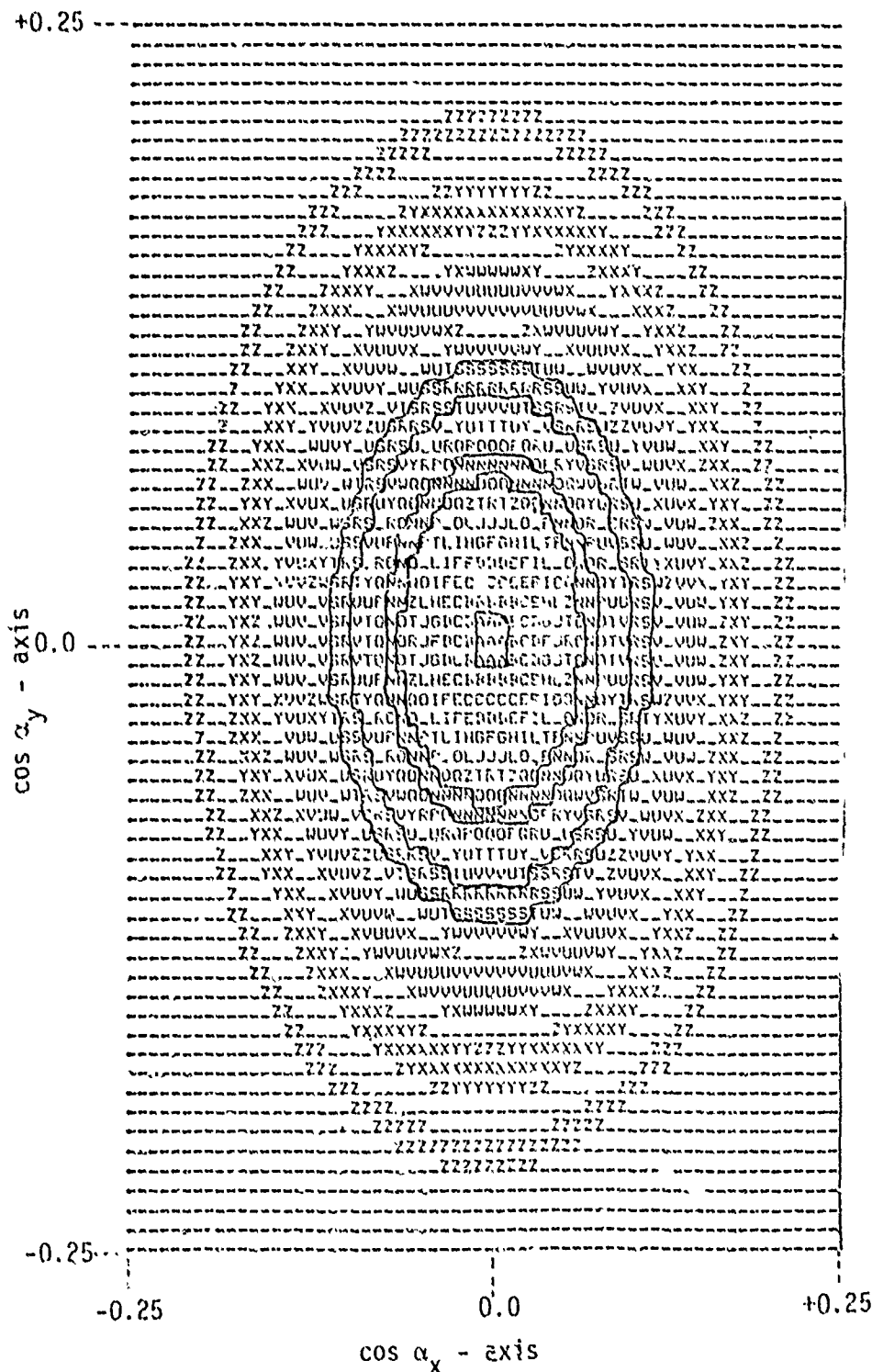


Figure 9. Far-field of cosine distribution (Plotted using RT14)

The Blackman function tapers very gently at the edge of the aperture and as a result produces very low sidelobes (13). The weighting function is shown in Figure 10 while its transform is shown in Figure 11. The sidelobes are 58 dB down in Figure 11. The sacrifice for low sidelobes is a broadening of the main beam. In fact the 3 dB beamwidth is about twice the beamwidth of the same size array with rectangular weighting, as is in Figure 6. The Blackman weighting function is a variation of the cosine on a pedestal. It is the difference of two cosine on a pedestal functions plus a constant. The equation defining the Blackman is (23)

$$w(X) = 0.42 - 0.5 \cdot \cos\{(X/R+1) \cdot \pi\} + 0.08 \cdot \cos^2\{(X/R+1) \cdot \pi\} \quad (3.2)$$

where:     R = The radius or half span of the weighting function  
               X = Independent variable

The Kaiser weighting function is unique among the simpler weighting functions because it allows the designer a choice in compromising between main lobe width and sidelobe level (23). The equation for the Kaiser weighting is

$$w(X) = \frac{I_0\left\{\frac{K}{R} \sqrt{R^2 - X^2}\right\}}{I_0(K)} \quad (3.3)$$

where:     K = The Kaiser trade-off variable between main lobe width and sidelobe amplitude  
               R = The radius or half-span of the weighting function  
               X = Independent variable



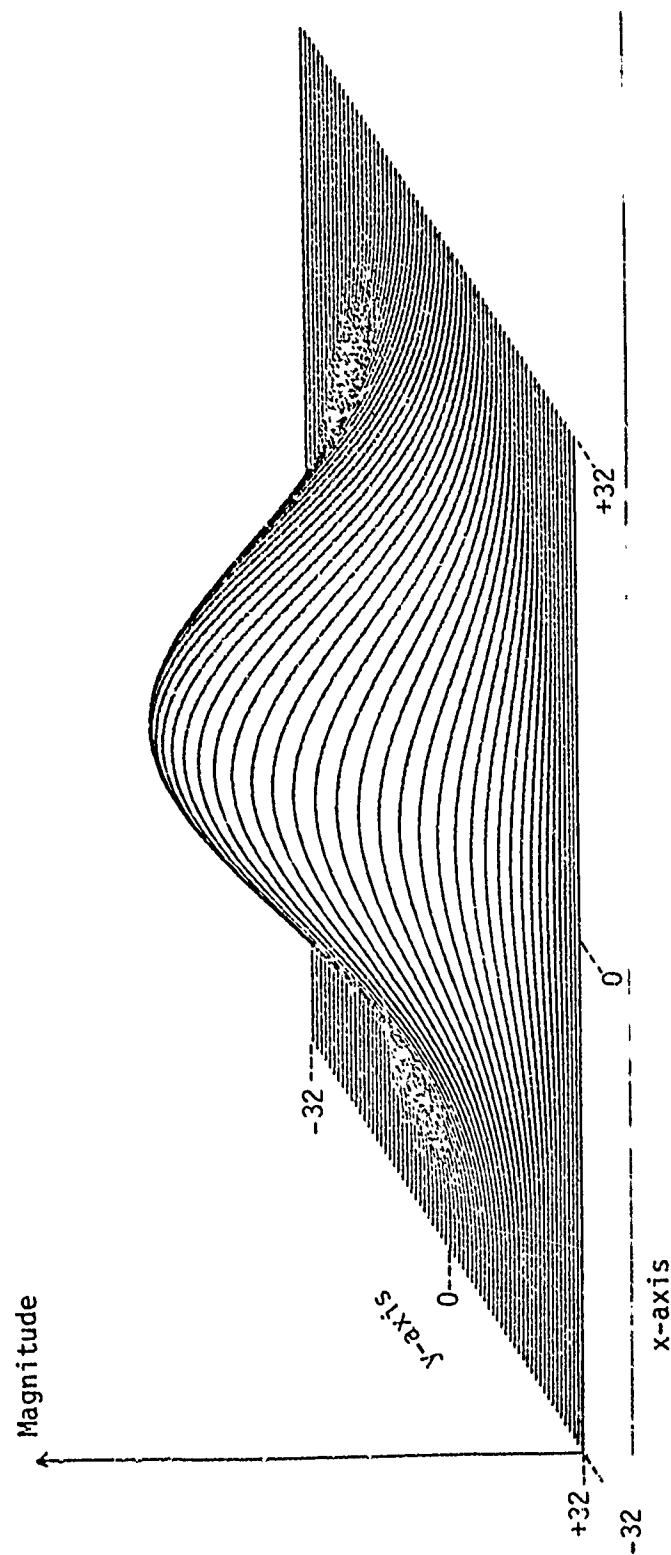


Figure 10. Blackman aperture current distribution.

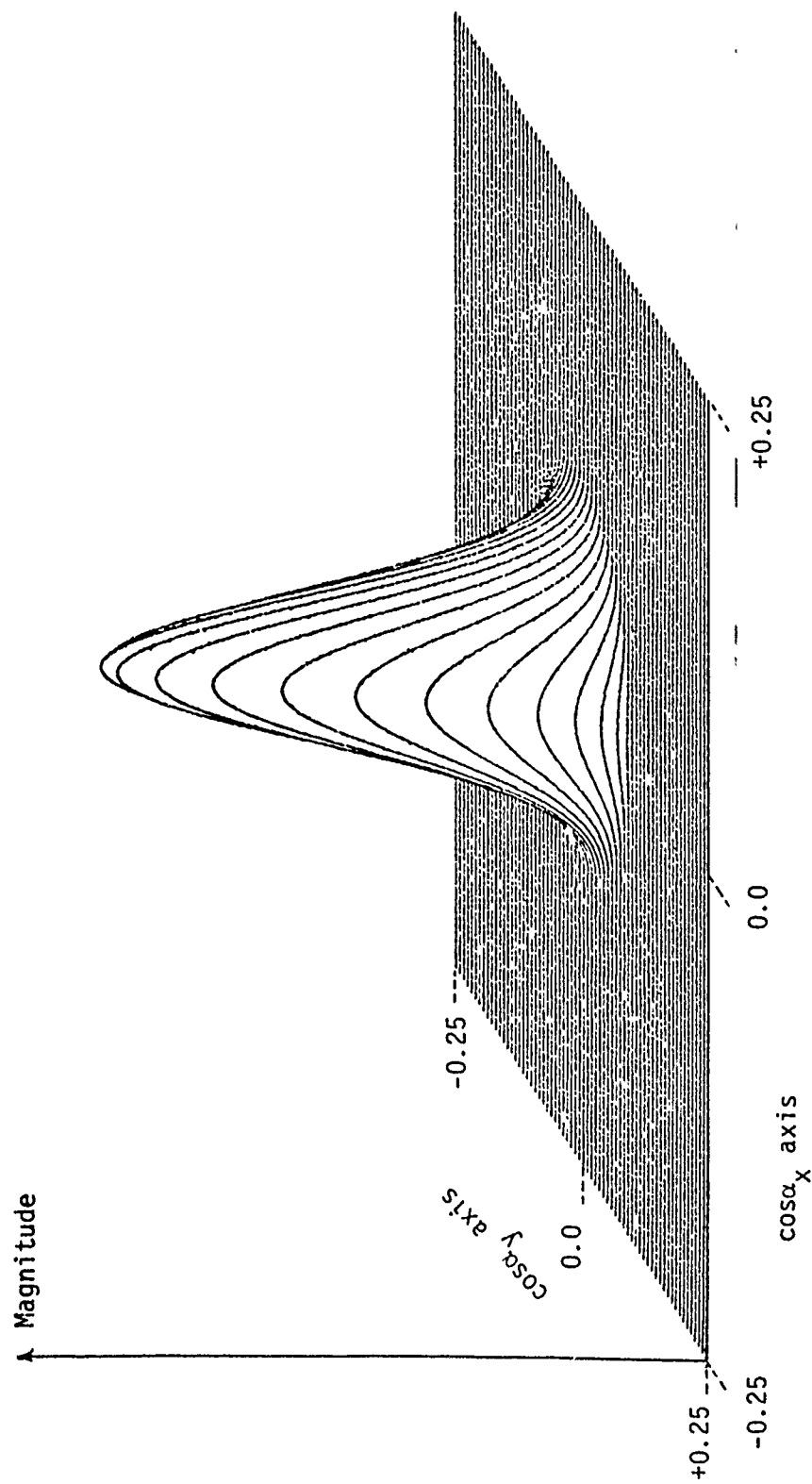


Figure 11. Far-field of Blackman distribution.

The range for the trade-off variable is  $2 \leq K \leq 8$ . Within these limits a wide range of choice is available. If the choice of  $K$  is close to 2, then a very narrow main lobe results at the sacrifice of higher sidelobes. An example of the weighting and its far-field are shown in Figure 12 and 13 respectively for a Kaiser variable equal to 2. If a Kaiser variable closer to 8 is chosen, the results are very low sidelobes at the sacrifice of a wider main lobe. For a Kaiser variable equal to 8 the aperture and the far-field are seen in Figures 14 and 15 respectively. The sidelobe level for the far-field in Figure 13 is 22 dB as compared to a 58 dB level in Figure 15. It should also be noted that the main lobe of the far-field in Figure 13 is  $3.0^\circ$  compared to the main lobe of Figure 15 which has a main lobe width of  $5.0^\circ$ .

The Bartlett or triangular window is perhaps the simplest of the weighting functions. Its equation is (23)

$$w(x) = 1 - x/R \quad (3.4)$$

where:  $R$  = The radius or half-span of the weighting function  
and  $x$  = The independent variable.

The sidelobe level of this weighting function is 32 dB down (24). An example of the weighting function is shown in Figure 16 while the far-field is shown in Figure 17. The sidelobes are indeed down by 32 dB but the main beam is about one and a half times as wide as for a uniform distribution. Here again the design trade-off is between sidelobe level and main lobe width.

The Taylor weighting distribution is perhaps the most sophisticated

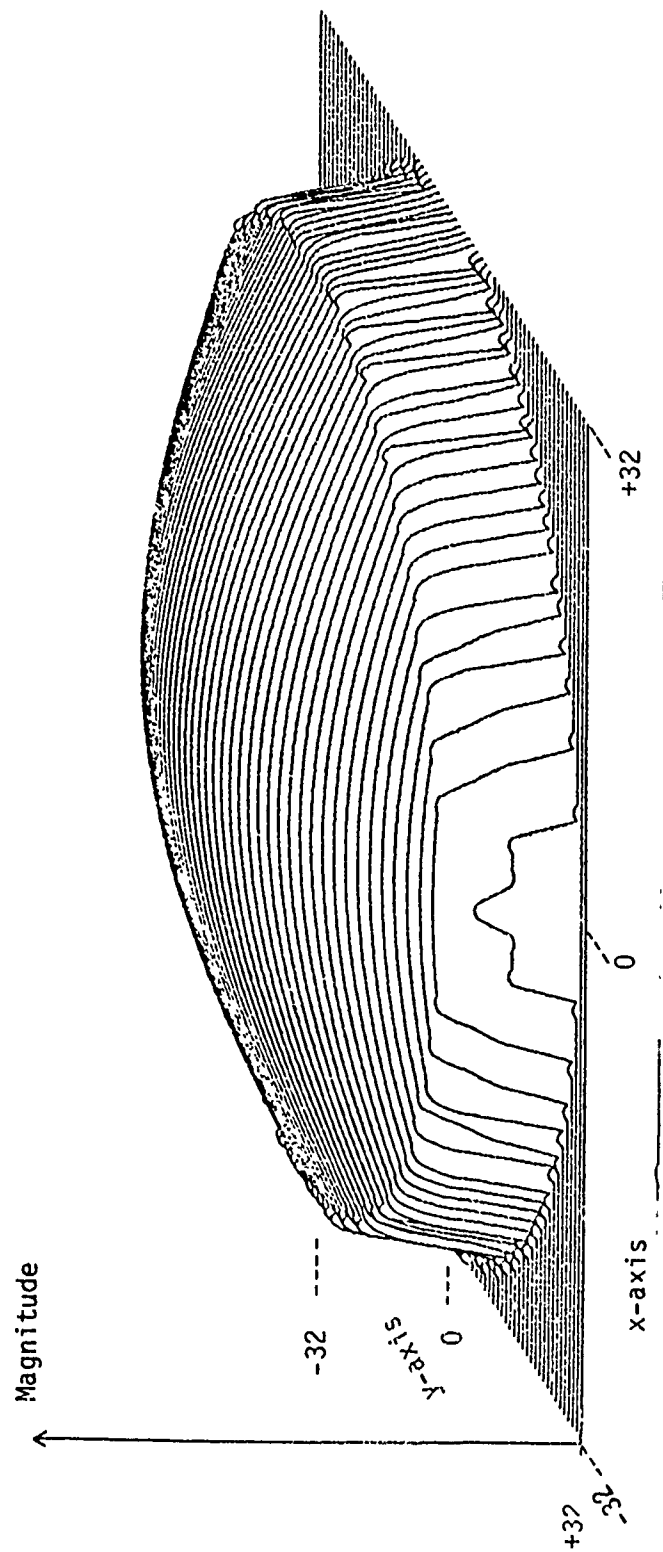


Figure 12. Kaiser aperture current distribution (Kaiser variable equal to 2).

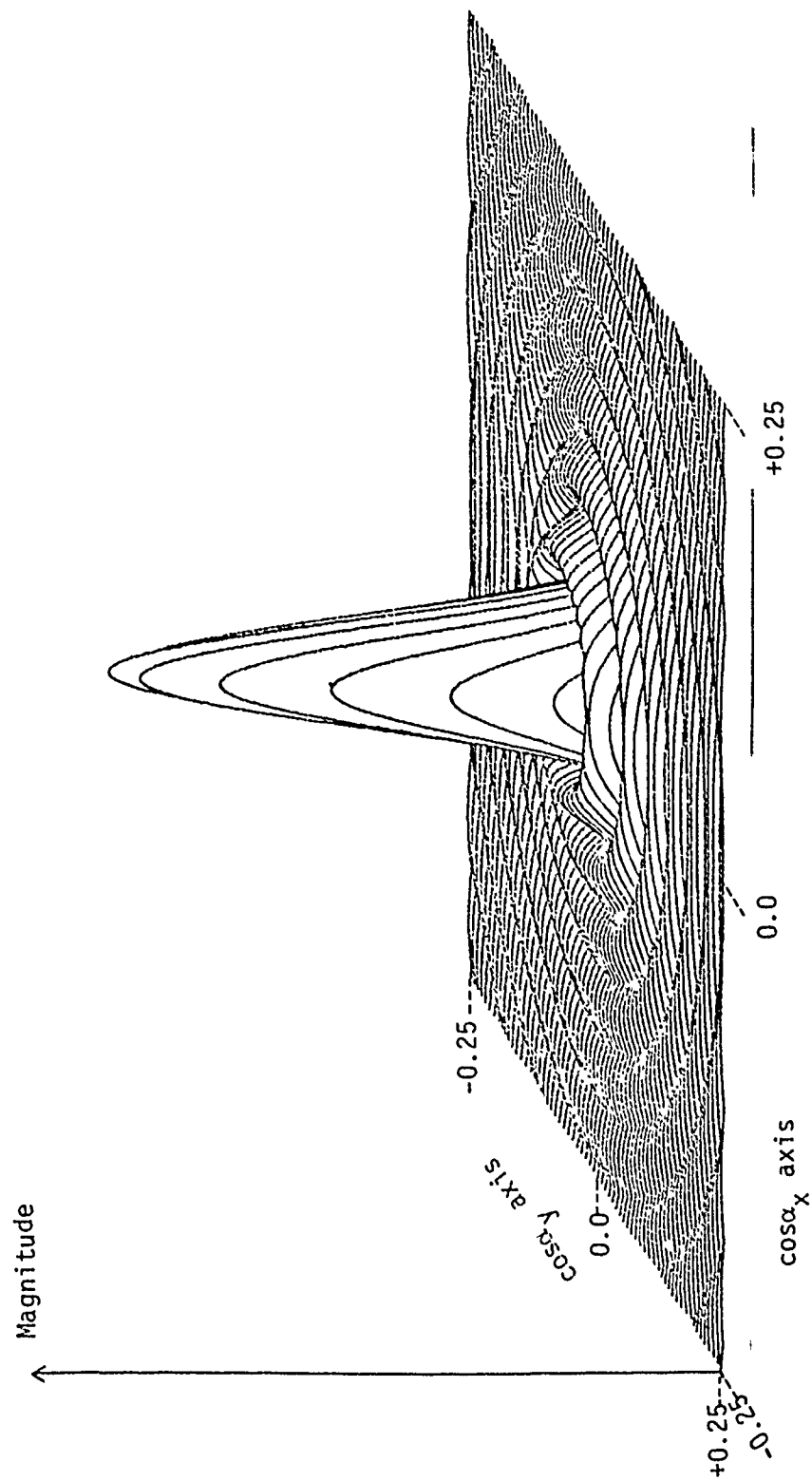


Figure 13. Far-field of Kaiser distribution (Kaiser variable equal to 2).

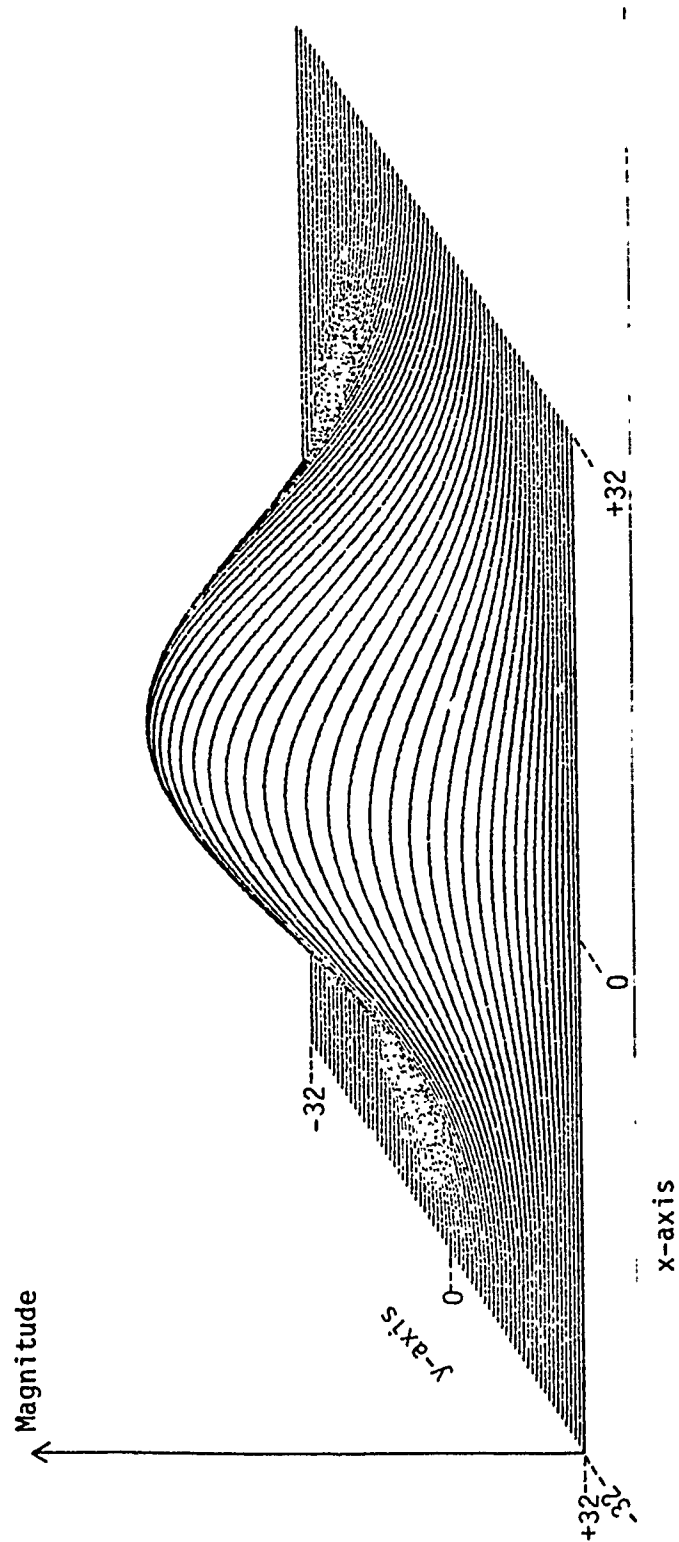


Figure 14. Kaiser aperture current distribution (Kaiser variable equal to 8).

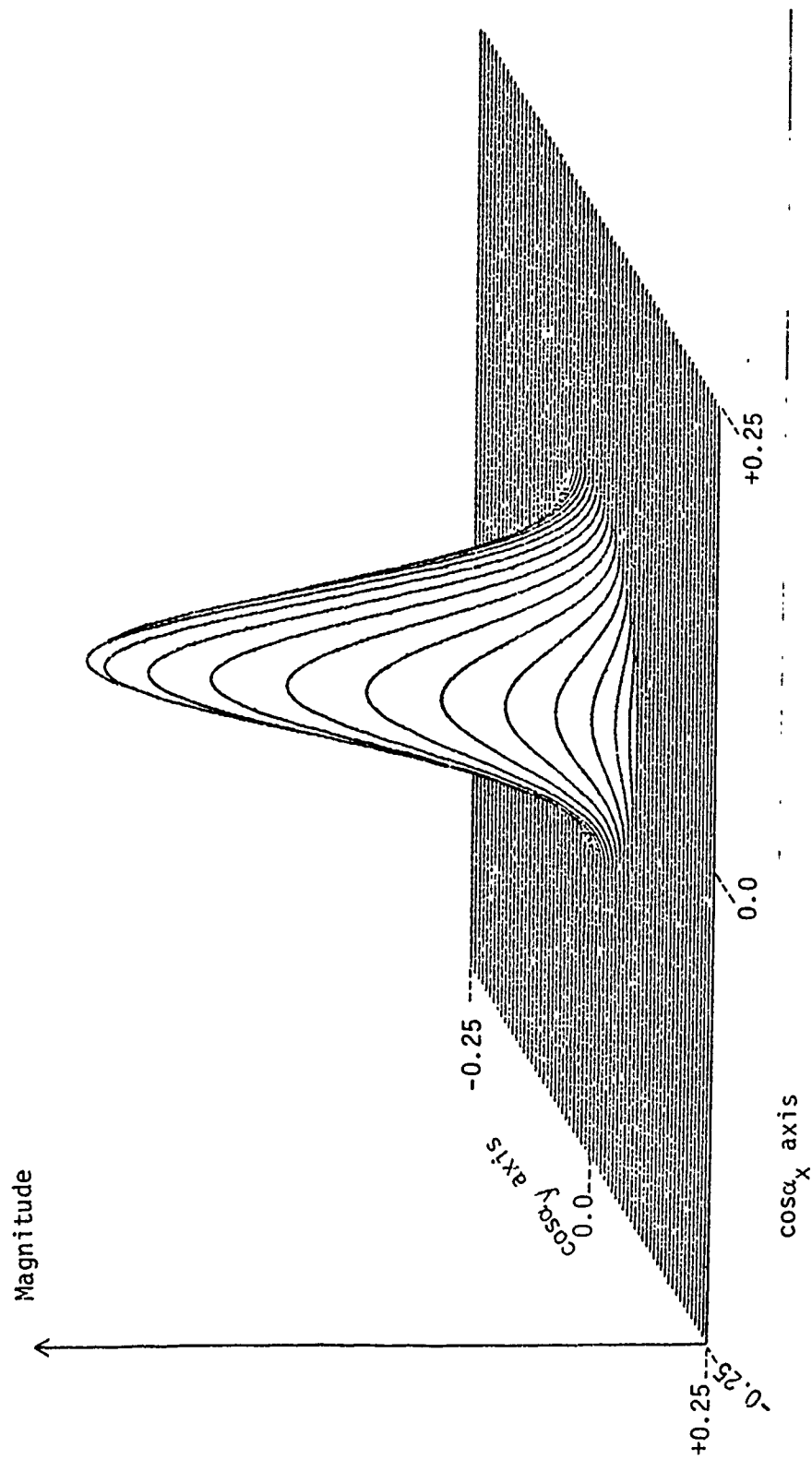


Figure 15. Far-field of Kaiser distribution (Kaiser variable equal to 8)

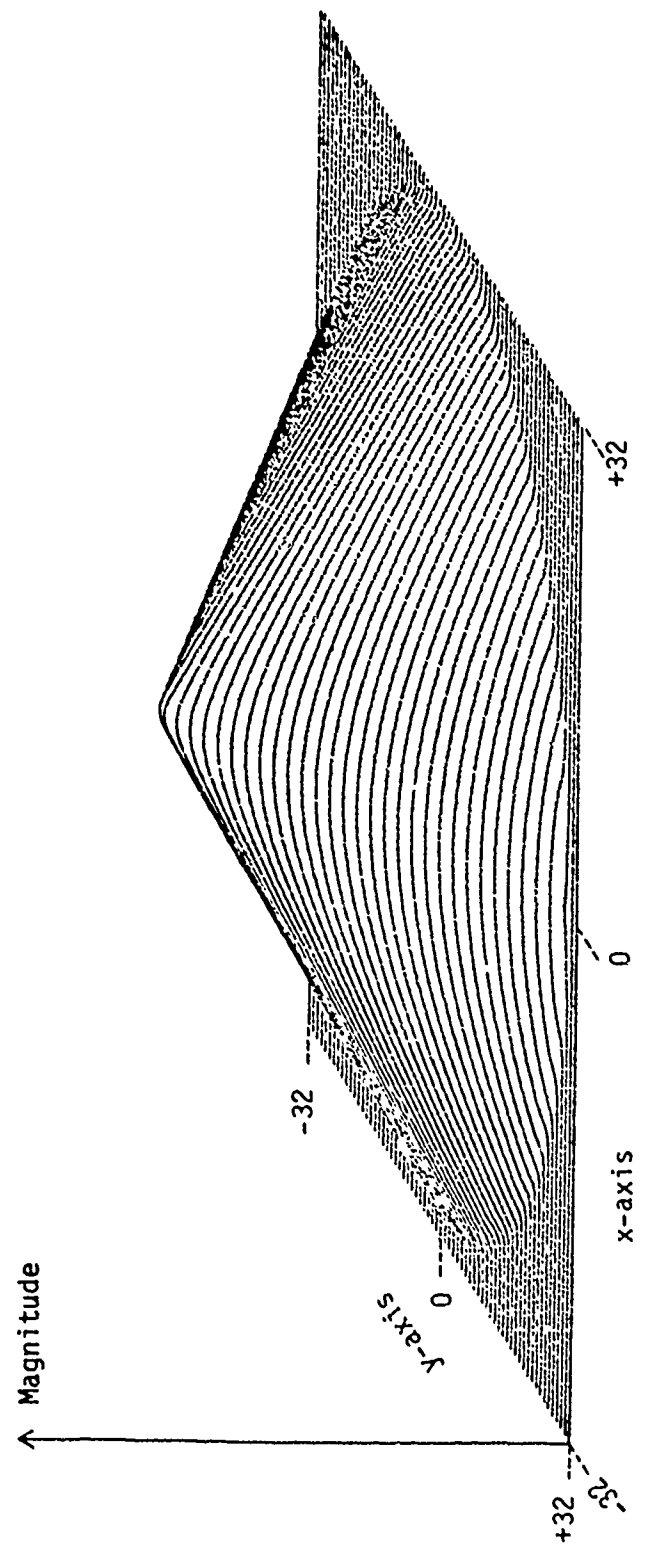


Figure 16. Triangular aperture current distribution.



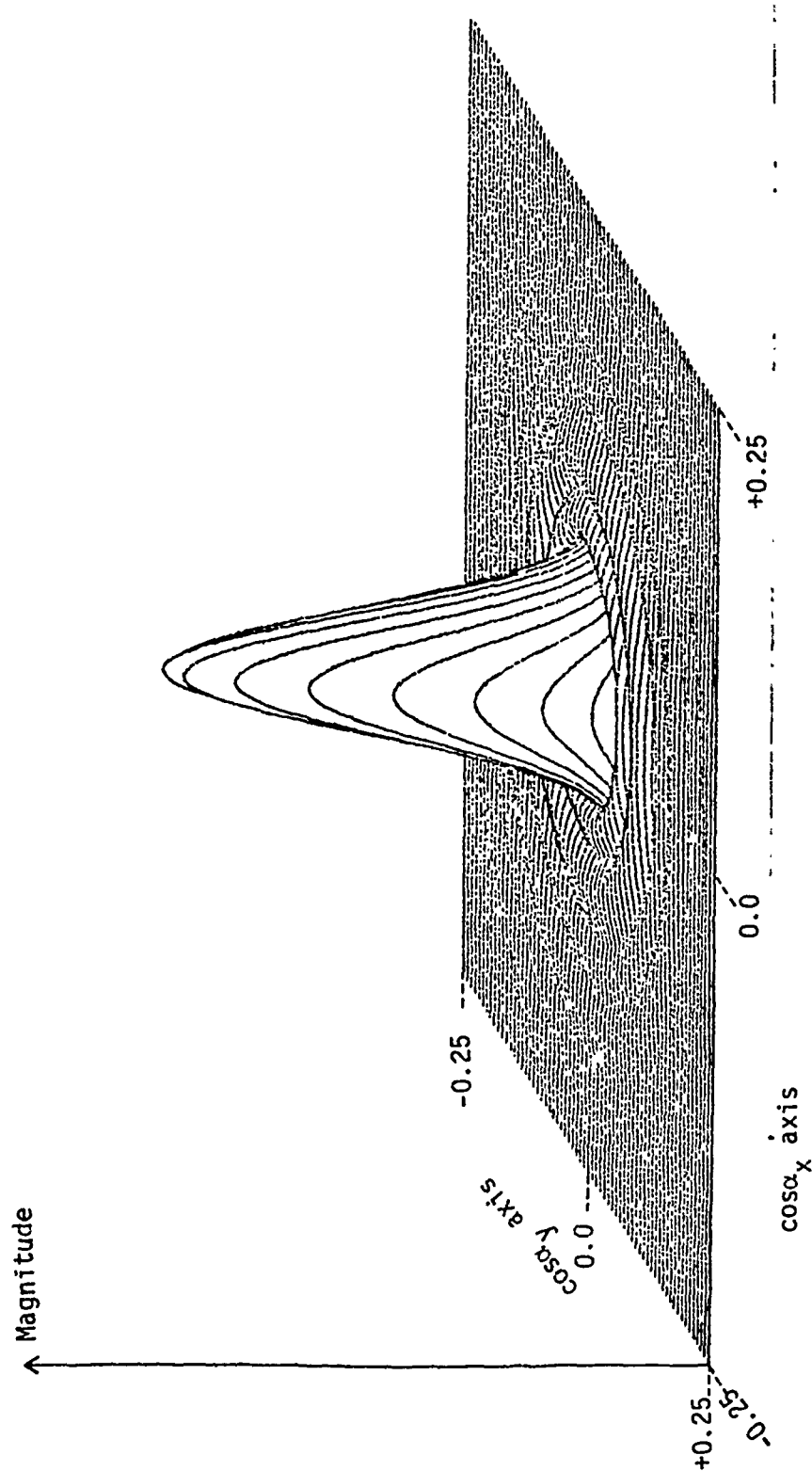


Figure 17. Far-field of triangular distribution.

weighting function available to the antenna designer (8-10). It allows the designer to approach the ideal Dolph-Chebyshev weighting function, the "ideal" criterion being the best main lobe width for a specified sidelobe level. The Taylor approaches this to any degree of accuracy that the designer may wish. The set of equations for the Taylor weighting for a circular aperture are given below (9,10).

$$w(P) = \frac{2}{\pi^2} \sum_{m=0}^{\bar{N}-1} \frac{J_0(\mu_m P) F(\mu_m, A, \bar{N})}{\{J_0(\pi \mu_m)\}^2} \quad (3.5a)$$

where:

$$P = \pi x/R \quad (3.5b)$$

X = Independent Variable

R = Radius of the weighting function

$$F(\mu_m, A, \bar{N}) = \begin{cases} 1 & , m = 0 \\ - J_0(\pi \mu_m) \prod_{n=1}^{\bar{N}-1} \left\{ 1 - \frac{\mu_m^2}{\sigma^2 [A^2 + (n-\frac{1}{2})^2]} \right\} & \\ \frac{\prod_{n=1}^{\bar{N}-1} \left\{ 1 - \left( \frac{\mu_m}{\mu_n} \right)^2 \right\}}{n \neq m} & \\ 0 & m = 1, 2, \dots, \bar{N} \\ & , m = \bar{N} + 1, \dots \end{cases} \quad (3.5c)$$

$$A = \frac{\cosh^{-1} \eta}{\pi} \quad (3.5d)$$

$$\eta = \text{antilog} (DB/20.0) \quad (3.5e)$$

DB = Design sidelobe amplitude in dB

$$\alpha = \frac{\mu_N}{\sqrt{\lambda^2 + (N-1)^2}} \quad (3.5f)$$

$\mu_n$  = The zeros of the Bessel function

$$J_1(\mu_n) = 0, n = 1, 2, \dots$$

N = The number of equal amplitude sidelobes desired.

The Taylor weighting function may be made to approach the ideal Dolph-Chebyshev function. This is achieved by choosing larger values of N. The value of N also determines the number of equal height sidelobes in the far-field. The sidelobe level decreases monotonically after the Nth sidelobe. For a given sidelobe level and N the main beam associated with the Taylor distribution is the smallest of any weighting function for the given sidelobe level. The articles by Taylor and Hansen give more insight and discussion on this weighting function (8-10). An example of the Taylor weighting for a 20 dB design and N equal to 10 is shown in Figure 18. The corresponding far-field is shown in Figure 19. Notice the equal sidelobes in Figure 19 compared to monotonically decreasing sidelobes of the uniform distribution of Figure 3. This is the characteristic feature of the Taylor weighting. The sidelobes remain equal for the required design number which in this case is 10.

The Bessel weighting function is produced by the feed system of some mechanical dish antennas (12). The weighting is such that the

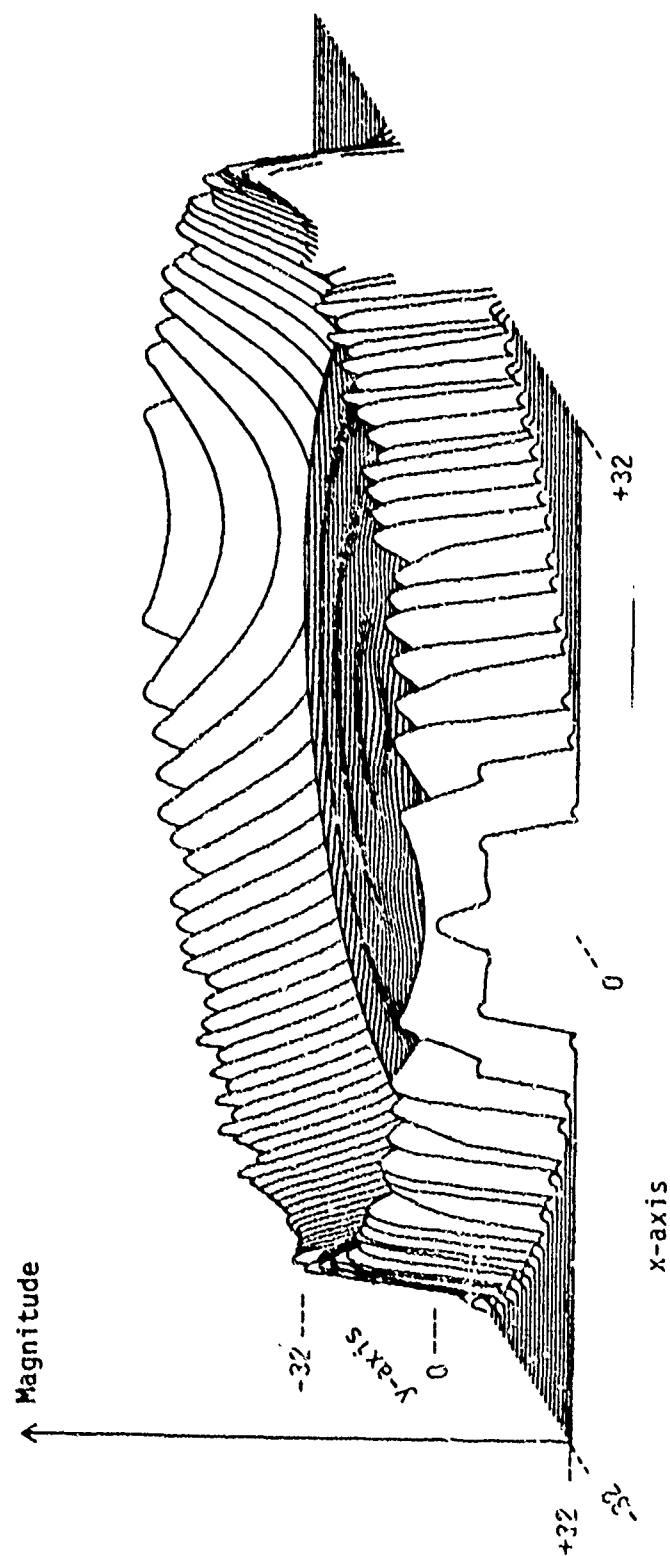


Figure 18. 20 dB Taylor aperture current distribution with  $\bar{N} = \omega$ .

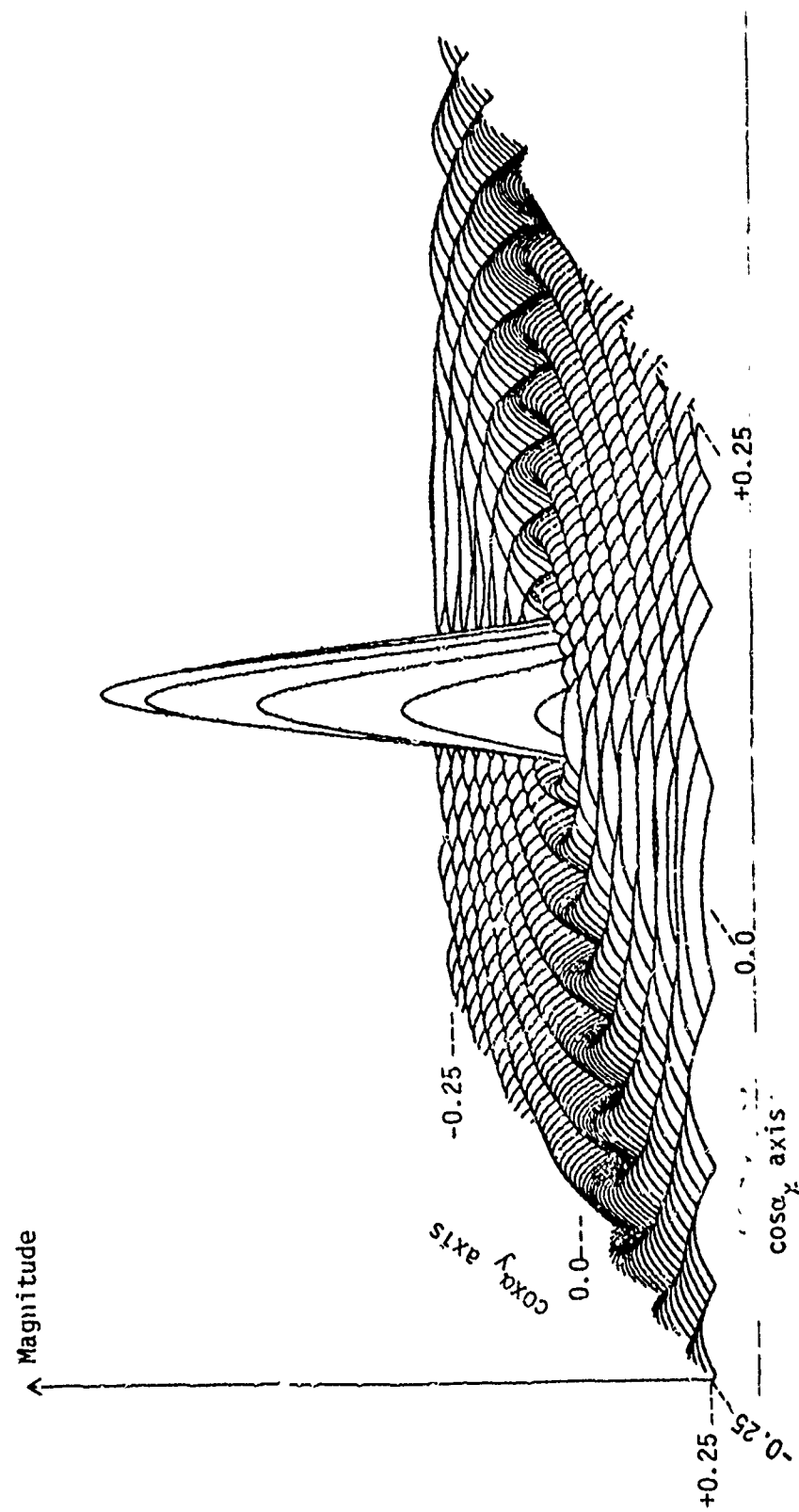


Figure 19. Far-field of 20 dB Taylor distribution with  $\bar{N} = 10$ .

first zero crossing of the Bessel function is at the edge of the aperture. An example of an ideally positioned Bessel weighting is shown in Figure 20. If the zero crossing is inside the aperture, then the current distribution appears to be on a pedestal. If the zero crossing is outside the aperture, then the current distribution may have negative amplitude at the edge. The far-field of the aperture distribution in Figure 20 is shown in Figure 21. The equation for the Bessel weighting is

$$w(x) = B_{\max} J_0(Xr_s) \quad (3.6)$$

where:

- $X$  = Independent Variable
- $B_{\max}$  = The maximum weighting amplitude
- $r_s$  = The radius scaling constant

The sidelobe level of the Bessel weighting is 28 dB down from the main lobe which has a beamwidth of about  $3.4^\circ$ .

The cubic weighting produces a difference pattern in the far-field which is used in monopulse tracking radar (12). The equation for the cubic weighting is

$$w(x) = C_{\max} x(x+R)(x-R) \quad (3.7)$$

where:

- $X$  = Independent Variable
- $R$  = The half-span of the weighting function
- $C_{\max}$  = Amplitude scaling constant

This weighting may only be used with rectangular apertures and produces

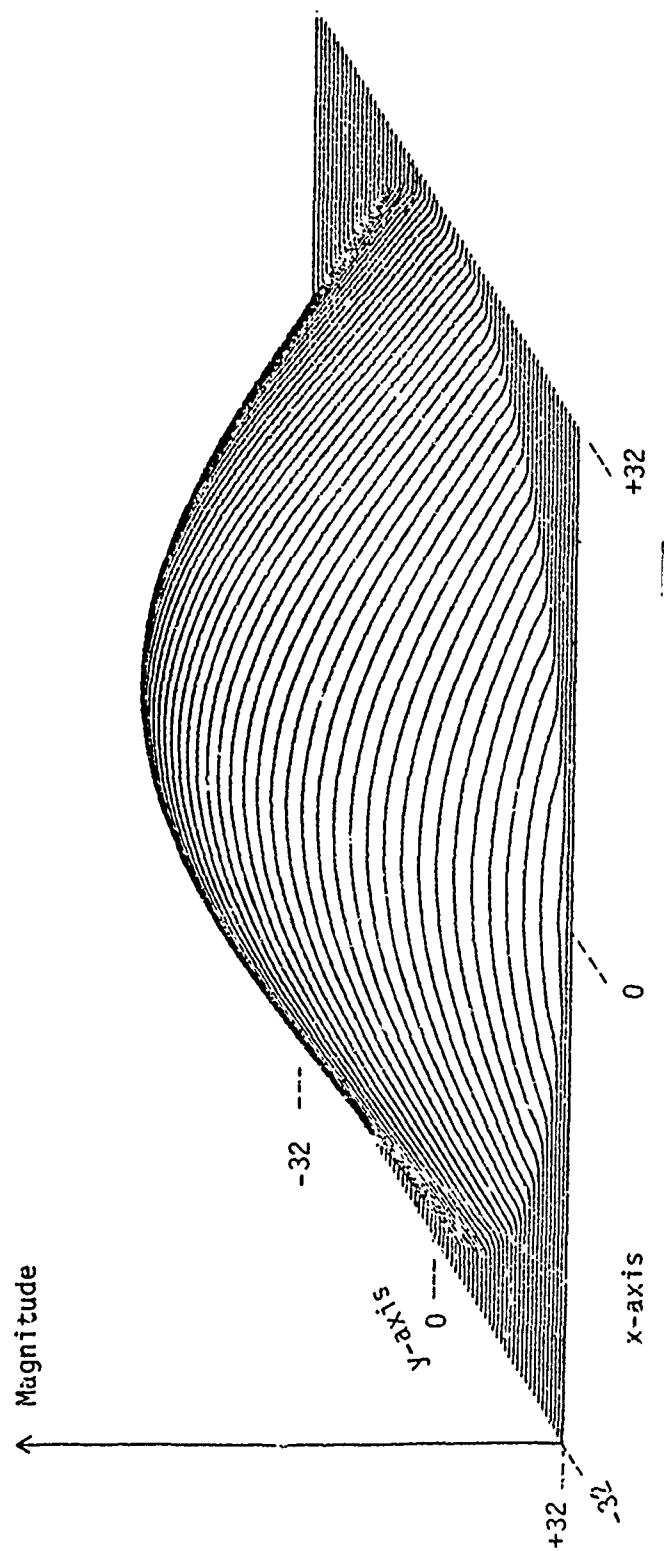


Figure 20. Bessel aperture current distribution.

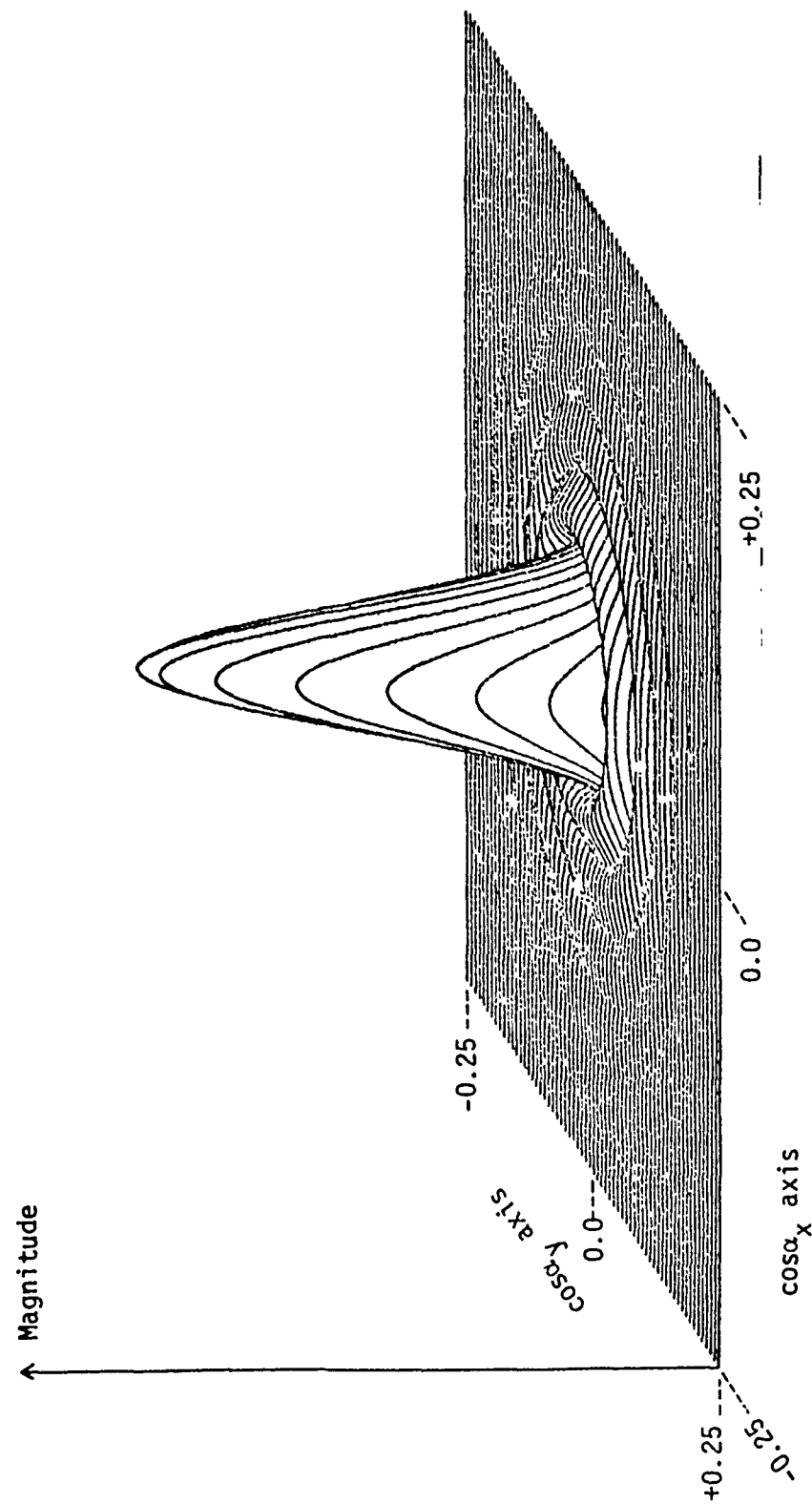


Figure 21. Far-field of Bessel distribution.



only 13 dB sidelobes. The weighting and its far-field are shown in Figure 22 and Figure 23, respectively.

The Bayliss weighting function is the first derivative of the Taylor weighting function and produces a difference pattern which is similar to the Taylor in many respects (25). The design criterion however is slightly different than the Taylor. The criterion is that for a given sidelobe level the slope at  $\theta = 0$  in the far-field must be a maximum. This again produces equal sidelobes just as did the Taylor. A design sidelobe level and a value for  $\bar{N}$  are chosen to produce  $\bar{N}$  equal sidelobes in the far-field. The equations defining the Bayliss weighting are given below (25).

$$w(p) = \cos(\psi) \sum_{m=0}^{\bar{N}-1} B(m) J_1(\pi \mu_m) \quad (3.8a)$$

where:  $P = \pi x/R$  (3.8b)

$x$  = Independent variable

$R$  = Radius of the weighting function

$\psi$  = The azimuth angle in the aperture plane

$\mu_m$  = zeros of the Bessel function

$$J_1'(\mu_m \pi) = 0, m = 0, 1, \dots$$

$$B(m) = \begin{cases} -jC2\mu_m^2 \frac{\prod_{n=1}^{\bar{N}-1} \{1 - (\frac{\mu_m}{\mu_n})^2\}}{\prod_{k=0, k \neq m}^{\bar{N}-1} \{1 - (\frac{\mu_m}{\mu_k})^2\}}, & m = 0, 1, \dots, \bar{N} - 1 \\ 0, & m = \bar{N}, \bar{N} + 1, \dots \end{cases} \quad (3.8c)$$

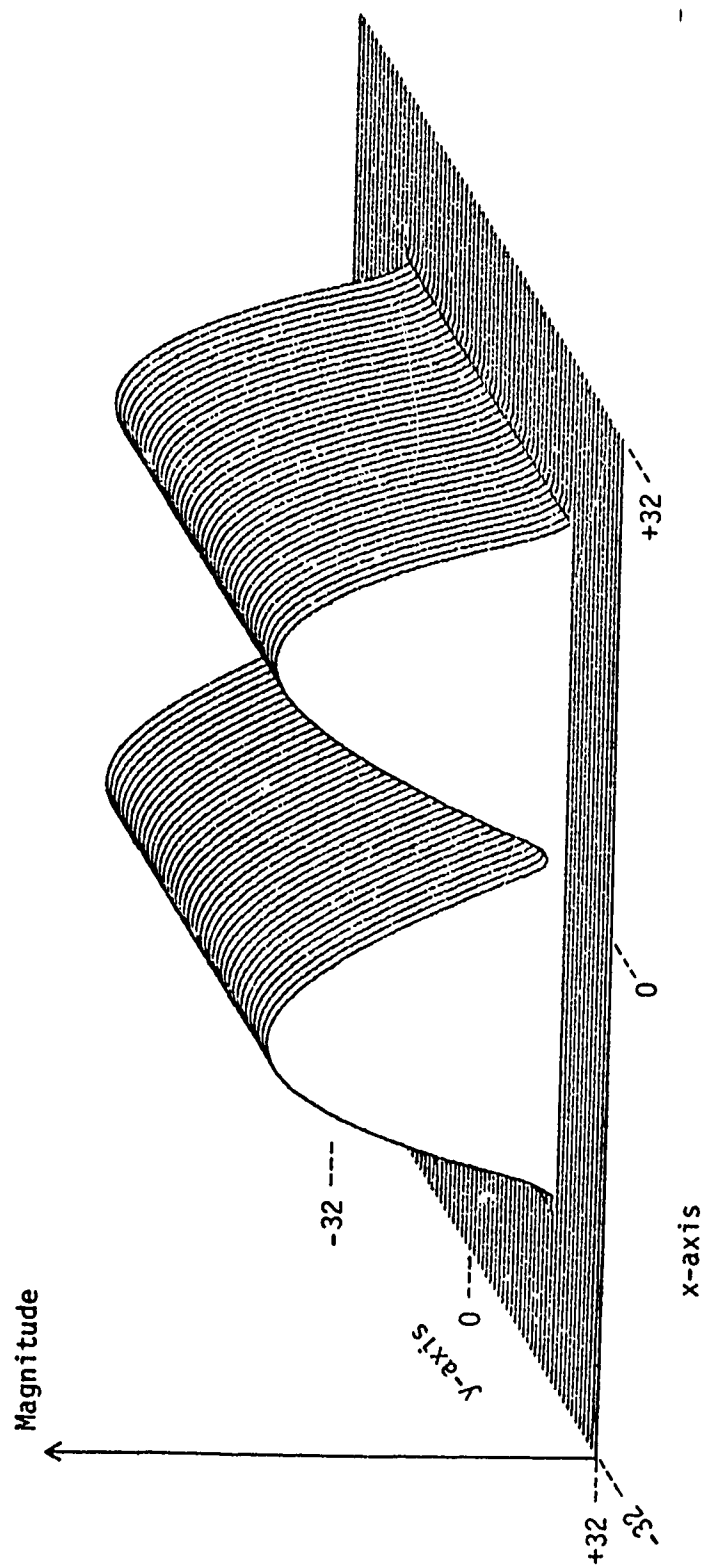


Figure 22. Cubic aperture current distribution.

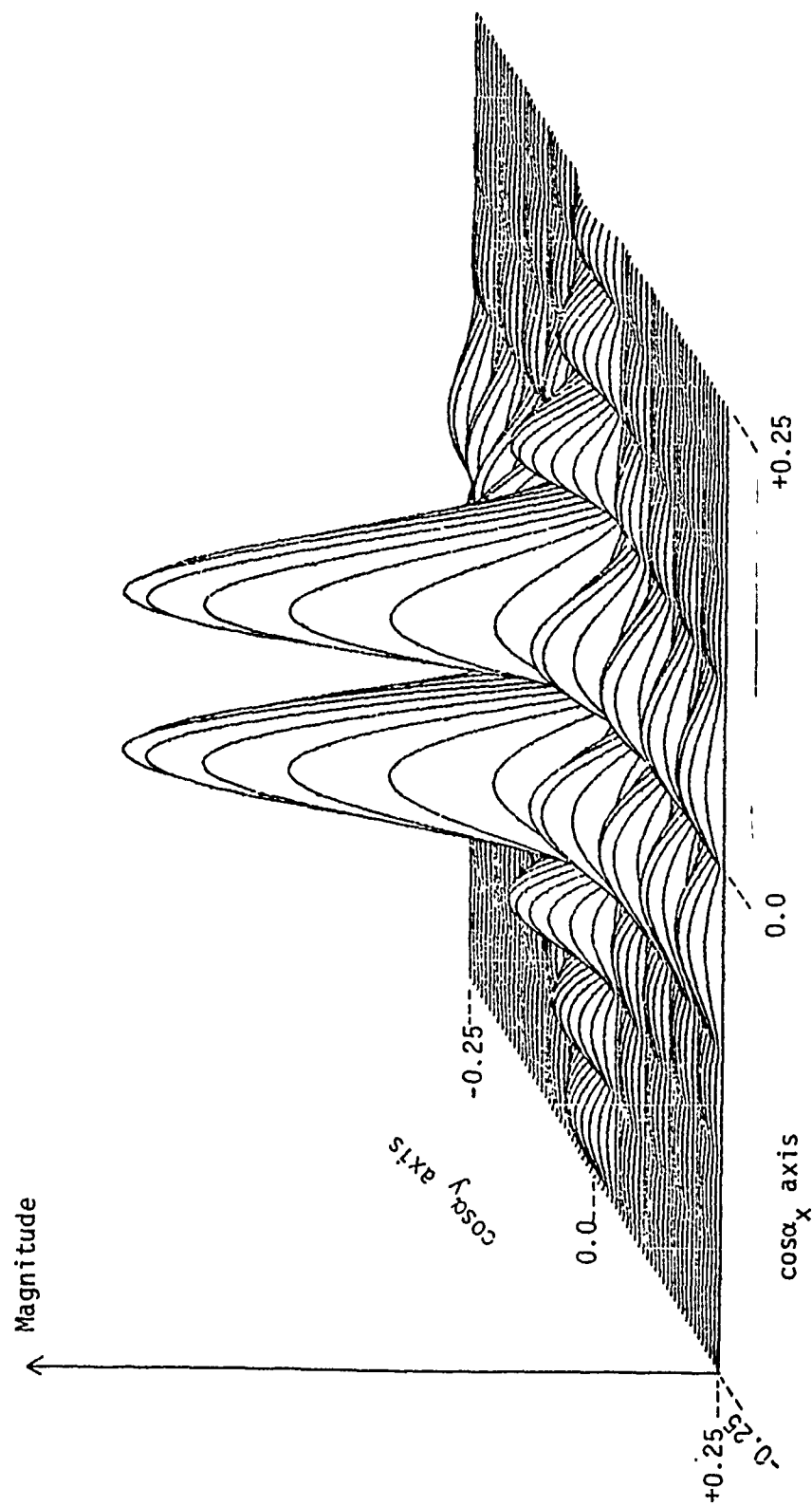


Figure 23. Far-field of cubic distribution.

$$Z_n = \begin{cases} 0, & n = 0 \\ \pm \xi_n, & n = 1, \dots, 4 \\ \pm (A^2 + n^2)^{1/2}, & n = 5, \dots \end{cases} \quad (3.8d)$$

$$\xi_1 = 0.9858302 + 0.0333885 \cdot DB + 0.000140 \cdot DB^2 - 0.0000019 \cdot DB^3 + 0.00000001 \cdot DB^4 \quad (3.8e)$$

$$\xi_2 = 2.00337487 + 0.1141548 \cdot DB + 0.0004159 \cdot DB^2 - 0.00000373 \cdot DB^3 + 0.00000001 \cdot DB^4 \quad (3.8f)$$

$$\xi_3 = 3.00636321 + 0.00683394 \cdot DB + 0.00029281 \cdot DB^2 - 0.00000161 \cdot DB^3 \quad (3.8g)$$

$$\xi_4 = 4.00518423 + 0.00501795 \cdot DB + 0.00021735 \cdot DB^2 - 0.00000088 \cdot DB^3 \quad (3.8h)$$

$$A = \frac{\cosh^{-1} \eta}{\pi} \quad (3.8i)$$

$$\eta = \text{antilog}(DB/20.0) \quad (3.8j)$$

$$\sigma = \frac{\mu_N}{Z_N} \quad (3.8k)$$

$$1/C = ((p_0 \sigma \pi)^2 - 1) J_1(\sigma p_0 \pi) .$$

$$\frac{\prod_{n=1}^{\bar{N}-1} \{1 - (\frac{p_0}{Z_n})^2\}}{\prod_{n=0}^{\bar{N}-1} \{1 - (\frac{\sigma p_0}{\mu_n})^2\}} \quad (3.8m)$$

$$P_0 = 0.4797212 + 0.01456692 \cdot DB - 0.00018739 \cdot DB^2 + 0.00000218 \cdot DB^3 - 0.00000001 \cdot DB^4 \quad (3.8n)$$

The aperture current distribution for a Bayliss with a 20 dB design and  $\bar{N}$  equal to 10 is shown in Figure 24. The corresponding far-field is

shown in Figure 25. Notice that similar to the Taylor the sidelobes are approximately equal and that the main beams are quite narrow.

### 3.4 Beam Steering and Phase Quantization

Planar arrays are steerable in two dimensions, azimuth and elevation. For representation in  $\sin\theta$  space however, direction cosines may be used to determine the position of the beam (1). Given the two direction cosines of a steering angle, the distance from the origin to the beam in the aperture plane is determined. The distance is also the sine of the elevation angle  $\theta$ . The azimuth angle  $\phi$ , can be calculated from the direction cosines using the following equation:

$$\phi = \tan^{-1} \frac{\cos \alpha_y}{\cos \alpha_x} \quad (3.9)$$

where  $\cos \alpha_x$  = direction cosine in the x-direction  
 $\cos \alpha_y$  = direction cosine in the y-direction

The angle of elevation is defined in terms of the direction cosines as

$$\theta = \sin^{-1} (\cos^2 \alpha_x + \cos^2 \alpha_y)^{1/2} \quad (3.10)$$

Instead of using direction cosines directly in the simulation, two orthogonal angles measured from the vertical axis in the x-y and y-z plane define the position of the beam. If the two direction cosines of these angles are taken to be coordinates of a Cartesian coordinate system in the x-y plane, sometimes called the T-plane, the point defined by  $(\cos \alpha_x, \cos \alpha_y)$  defines the location of the beam (26). The

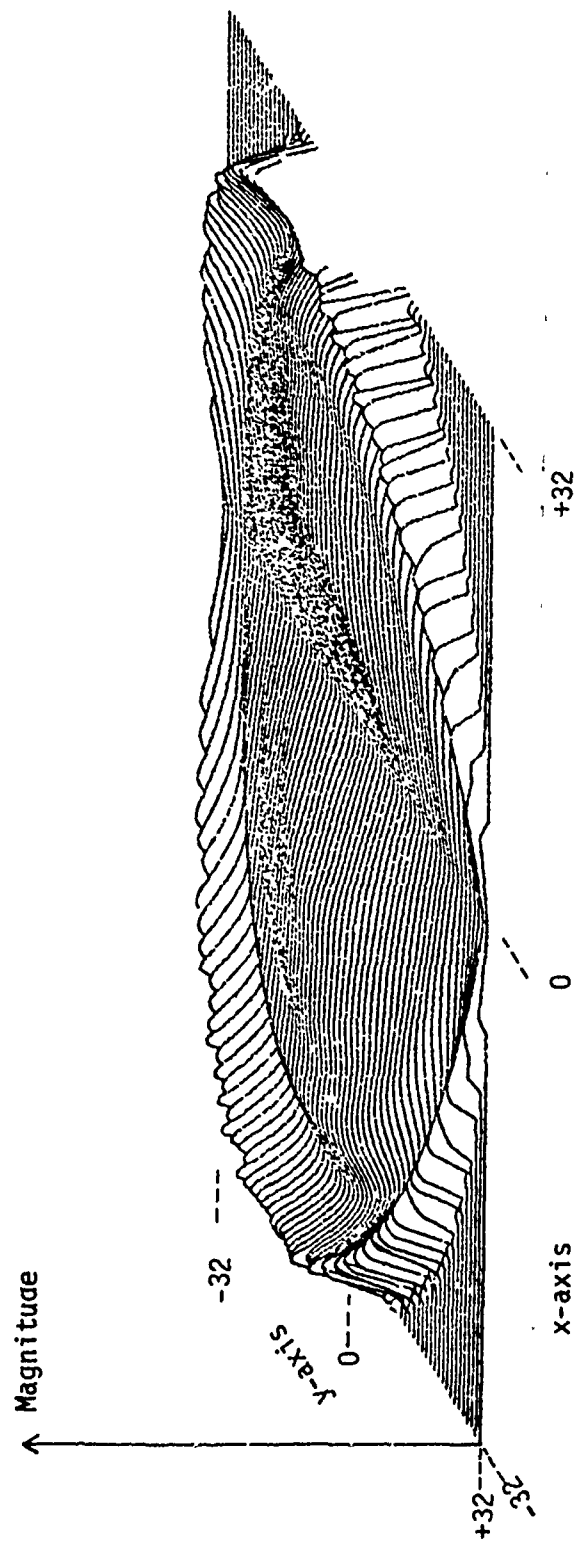


Figure 24. 20 dB Bayliss aperture current distribution with  $\bar{N} = 10$ .

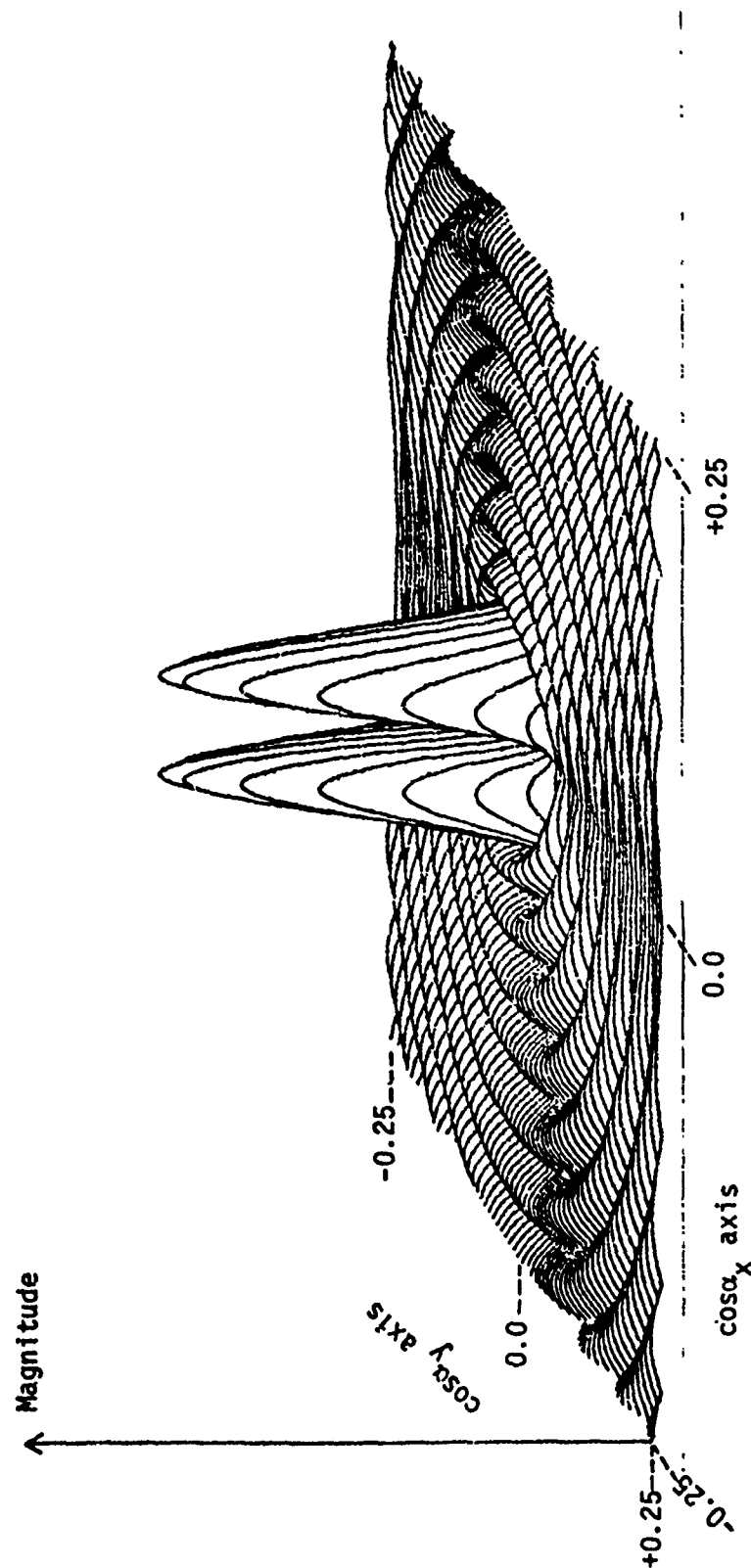


Figure 25. Far-field of 20 dB Bayliss distribution with  $\bar{N} = 10$ .

projection of the 3 dB beamwidth in the T-plane to a unit hemisphere above the plane defines the 3 dB beamwidth in the far-field. Figure 26 illustrates the projection of the beam in  $\sin \theta$  space to the beam in  $\theta$  space.

An example of an array steered to  $22.0^\circ$  in the y-z plane and  $15.0^\circ$  in the x-z plane is shown in Figure 27. The aperture has a uniform distribution and is the same size as the aperture in Figure 6. Notice that the shape of the beam and the sidelobes have not changed as a result of beam steering. This however is an illusion caused by representation in  $\sin \theta$  space (1). The real half-power beamwidth is the apparent beamwidth projected onto a unit hemisphere above the far-field plot. This gives a beamwidth that is larger than appears in the plot. The scanned beamwidth as a function of the broadside beamwidth and scan angle is given by the expression

$$\theta_B(\text{scanned}) = \frac{\theta_B(\text{broadside})}{\cos \theta_s} \quad (3.11)$$

See Figure 26 for an illustration of this effect.

Beam steering is implemented by applying an incremental phase shift to the elements of the array. This creates a shift in the phase plane of the aperture current distribution. Often digital phase shifters are used to make the incremental phase shift and they are controlled by a limited number of bits from an antenna control computer. The number of controlling bits determines the accuracy of the phase shifters in steering the beam. Since the maximum possible phase shift is  $360^\circ$ , the available phase shifts are in steps of



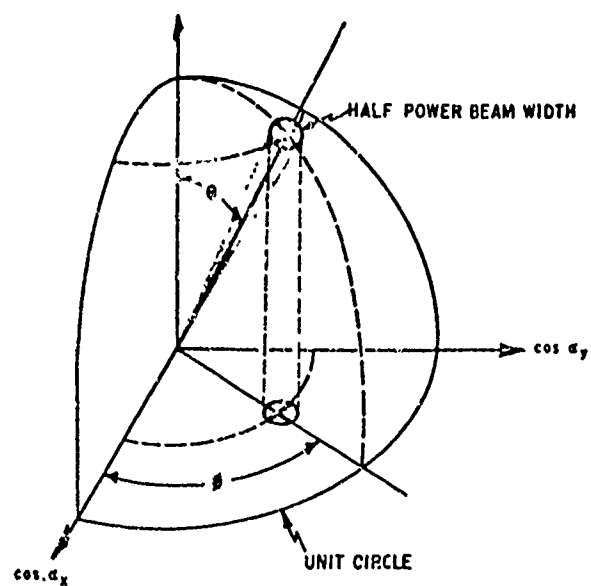


Figure 26. Projection of points on the  $\sin \theta$  plane onto the unit hemisphere.

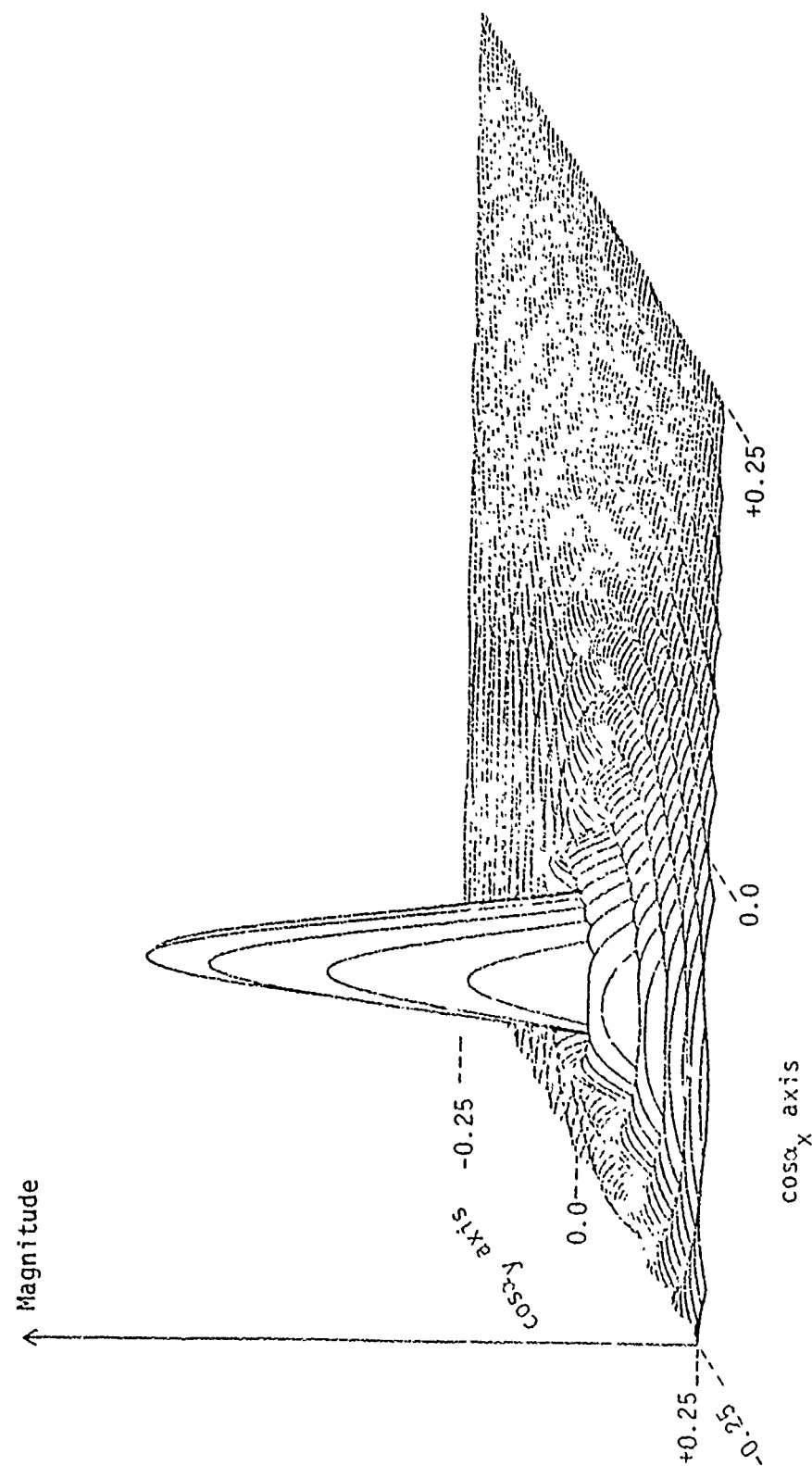


Figure 27. Far-field of uniform distribution with orthogonal beam steering angles  $(32.0^\circ, 15.0^\circ)$ ,  $n = 20$ .

$360/2^n$  where  $n$  is the number of control bits. In the example discussed above the number of control bits is very large ( $n = 20$ ) and gives extremely fine phase resolution. As a result of this steering accuracy the effects of phase quantization are not evident. In Figure 28, however, the number of control bits is equal to 3. This figure illustrates one of the effects of phase quantization error. The most obvious effect is the raising of the sidelobe level. Other effects that are not as obvious are the loss in main beam gain and the appearance of quantization lobes outside the range of the plot in Figure 28 (1). The quantization lobes may be seen in Figure 29 which is a 70 dB Taylor design ( $\bar{N} = 15$ ). The quantization lobes are introduced in the far-field as a result of the added periodic phase error caused by the mismatch in phase shifting ability and required phase shift. The peak sidelobes caused by quantization can be quite high and can cause a considerable degree of degradation in the far-field. The original design in Figure 29 is 70 dB and the peak sidelobe caused by quantization is only 18 dB down. The extremely low sidelobes are picked to illustrate the point, but in all designs the problem can arise.

### 3.5 Quadratic Phase Error

Quadratic phase error is a phase error that is proportional to the square of the distance from the origin and it occurs naturally in some antenna situations. It occurs in flared horn antennas and in lens type or reflector antennas when the feed is defocused along the

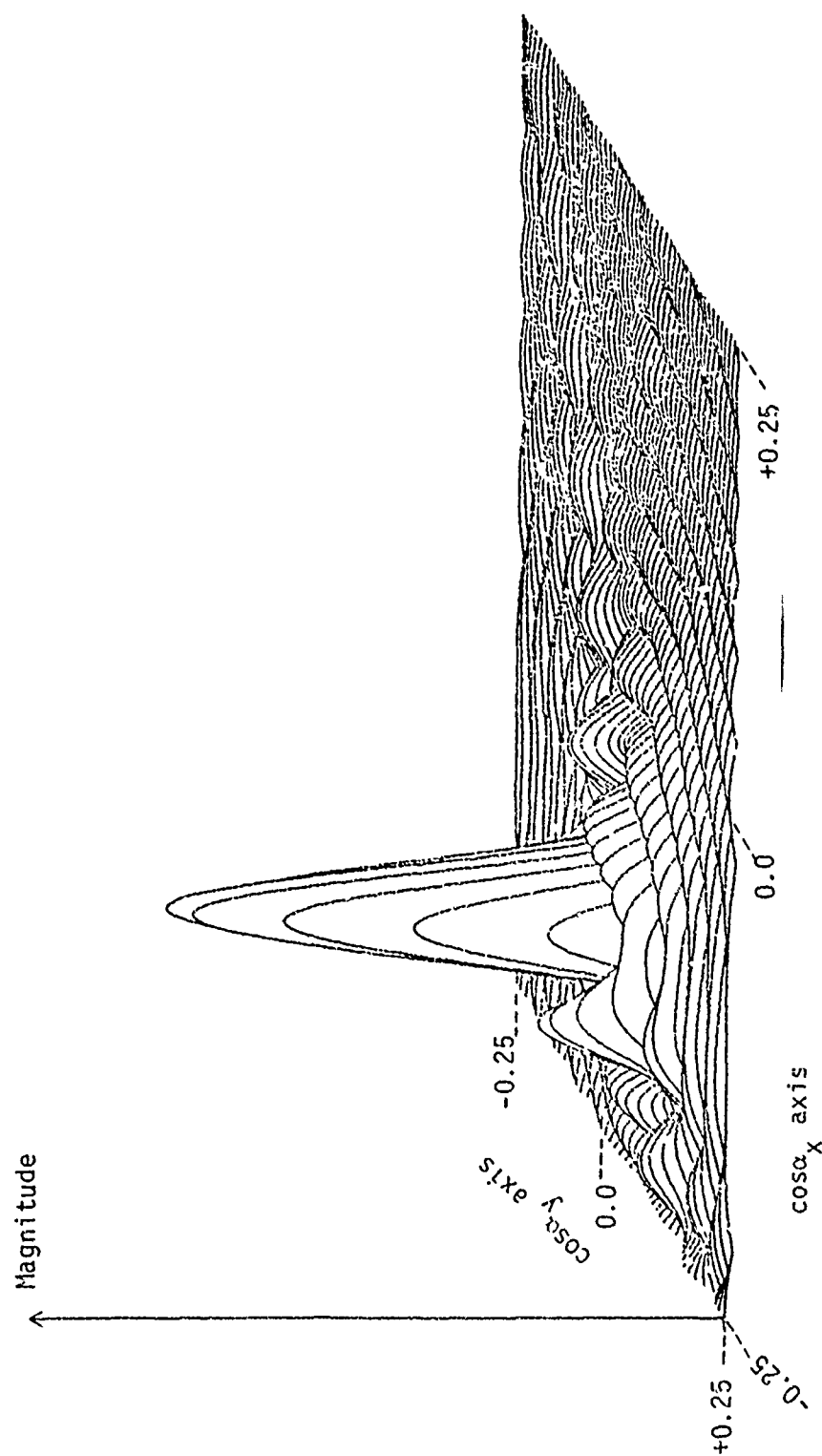


Figure 28. Far-field of uniform distribution with orthogonal beam steering angles  $(22.0^\circ, 15.0^\circ)$ ,  $n = 3$ .

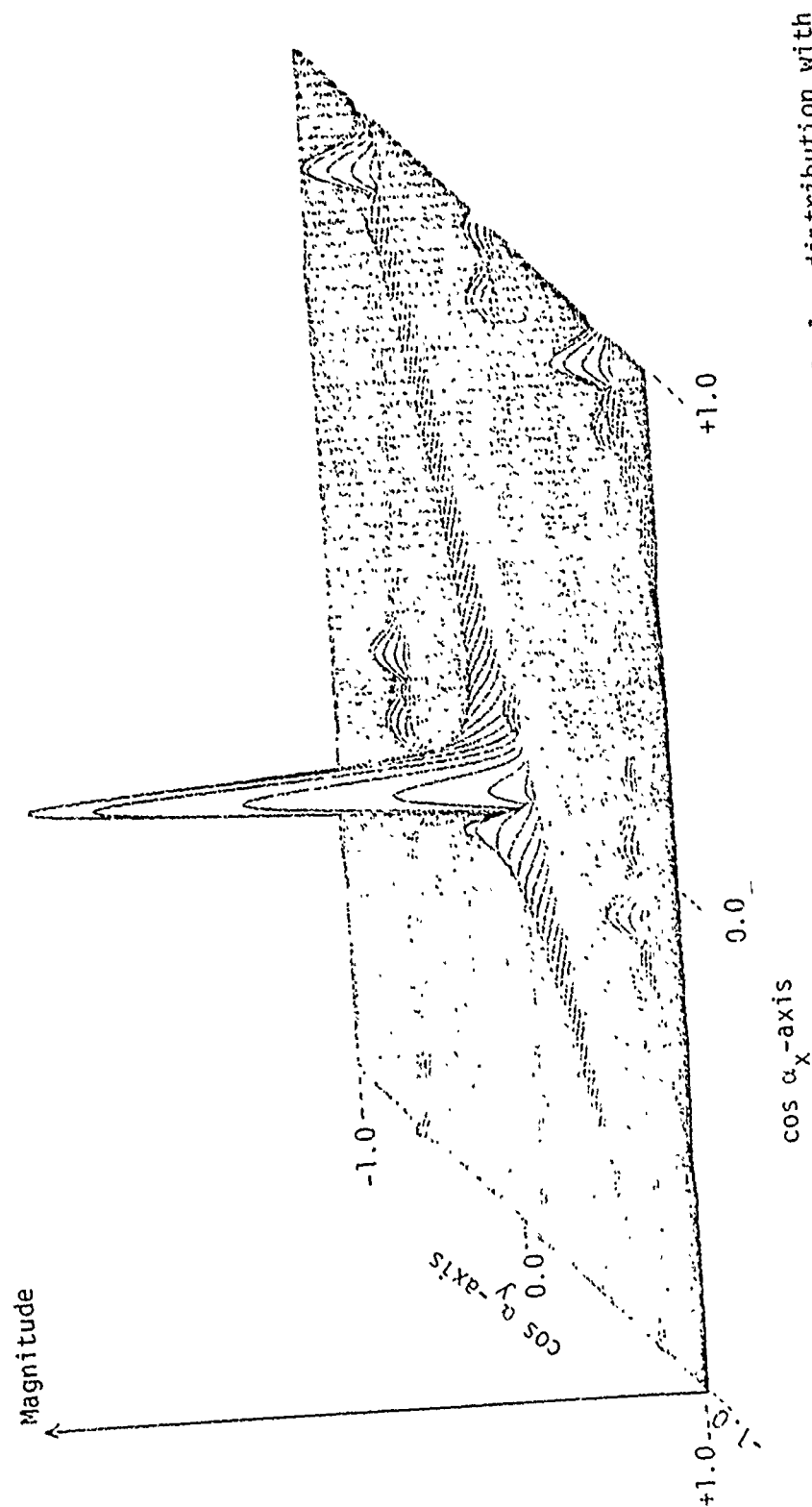


Figure 29. Complete visible region in far-field of 70 dB Taylor distribution with  $N = 15$  and orthogonal beam steering angles  $(22.00^\circ, 15.00^\circ)$ ,  $n = 3$ .

axis of symmetry (24). The effect of quadratic phase errors is also seen when the radiation pattern of an antenna is measured at a finite distance from the antenna. This is a result of the fact that the measurements are really being taken in the Fresnel region and not in the far-field. The approximations that are valid for the far-field are not all valid in the Fresnel region. One of the invalid approximations is that the quadratic phase term ignored for the far-field approximation may not be neglected in the Fresnel region.

For the Fresnel region the variations of  $r$  in the phase term  $\exp(-jkr)$  of Eq. 1.1 are approximated by a linear term and a quadratic term as follows (1).

$$r \approx z + \frac{(x+\xi)^2 + (y+\eta)^2}{2z} \quad (3.12)$$

For the far-field approximation, all the terms above the first order in Eq. 3.12 are neglected. This approximation may not be made in the Fresnel region.

Thus, if a measurement of the antenna pattern is not made at a very great distance, the quadratic phase character of the Fresnel region shows up. An example of the far-field of an antenna that has  $90.0^\circ$  of quadratic phase error at the edge of the aperture in the  $y$ - $z$  plane is shown in Figure 30. The radiation pattern checks with the data that Jasik presented in the Antenna Engineering Handbook (24). The main beam and the first sidelobes in Figure 30 are no longer separated by deep nulls as in the antenna far-field pattern without the phase error in Figure 5. Both antennas are square apertures with

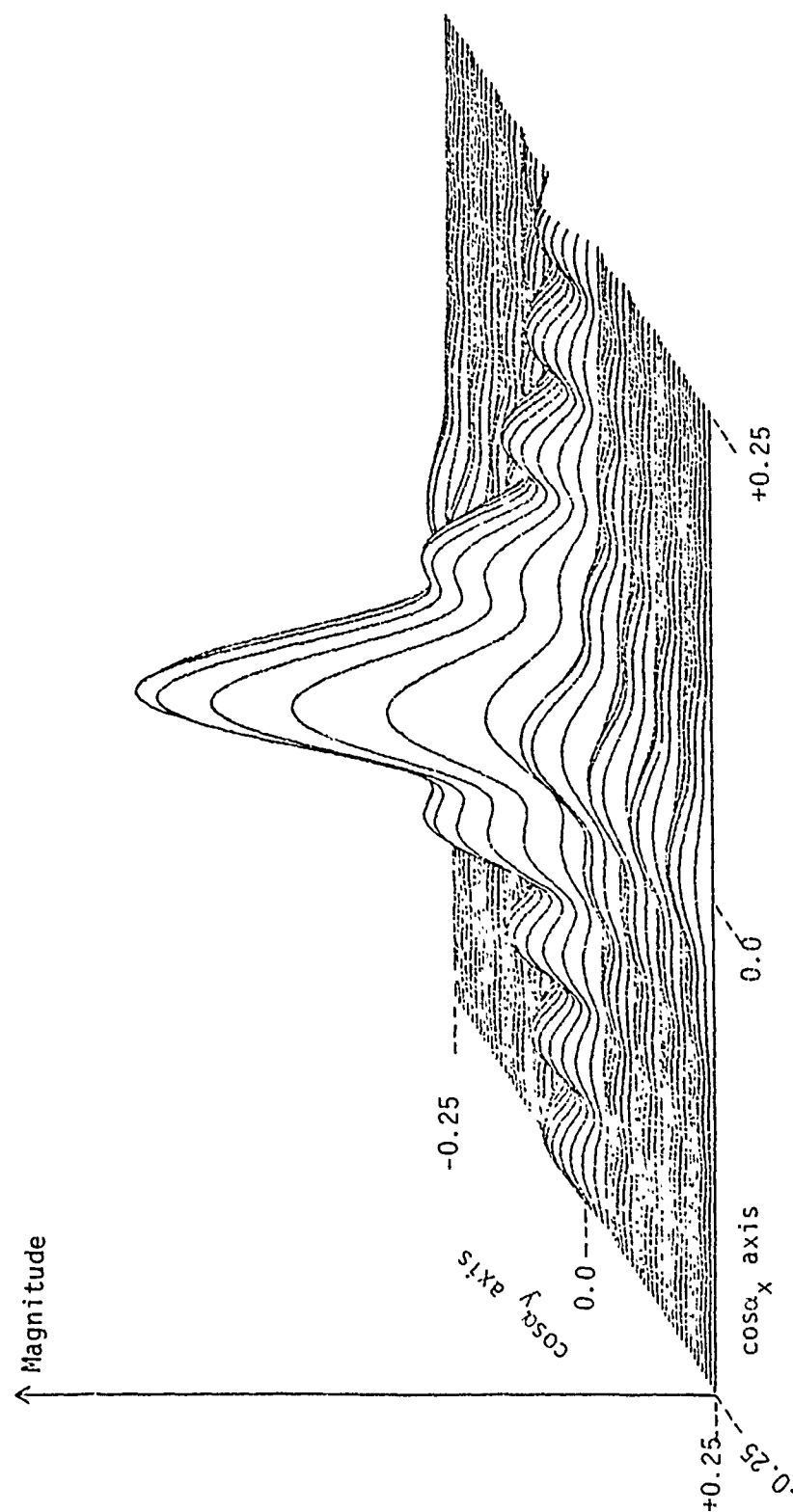


Figure 30. Far-field of uniform distribution with  $90.0^\circ$  of quadratic phase error at the edge of the aperture in the x-direction ( $40 \times 40$  rectangular aperture).

dimensions of 40 x 40 elements and uniform aperture current distributions. The effects of quadratic phase errors become apparent in light of this comparison.

### 3.6 Bessel Phase Error

In addition to the Bessel amplitude weighting that is a result of mechanical dish feed systems, Bessel phase errors may also arise. The two characteristics are independent and they may or may not occur simultaneously (12). The Bessel phase error has a peak at the center of the array and decreases to zero at the edge of the aperture. The nature of the variation with radius is a Bessel function. In some cases the structure of the feed and/or the antenna cause the edge of the aperture to lie either inside or outside the zero crossing of the Bessel function. If the edge of the aperture is inside the zero crossing, the phase errors appear to be on a pedestal much like the cosine on a pedestal weighting function. If the edge of the aperture is outside of the zero crossing of the Bessel function, the phase becomes negative for the remainder of the aperture assuming a small overshoot at the edge. The far-field pattern of an aperture with  $90.0^\circ$  peak phase error at the center of the array and with the zero crossings aligned exactly with the edge of the aperture is shown in Figure 31.

### 3.7 Statistical Loading or Space Tapering

The cost of building large phased array antennas is determined to



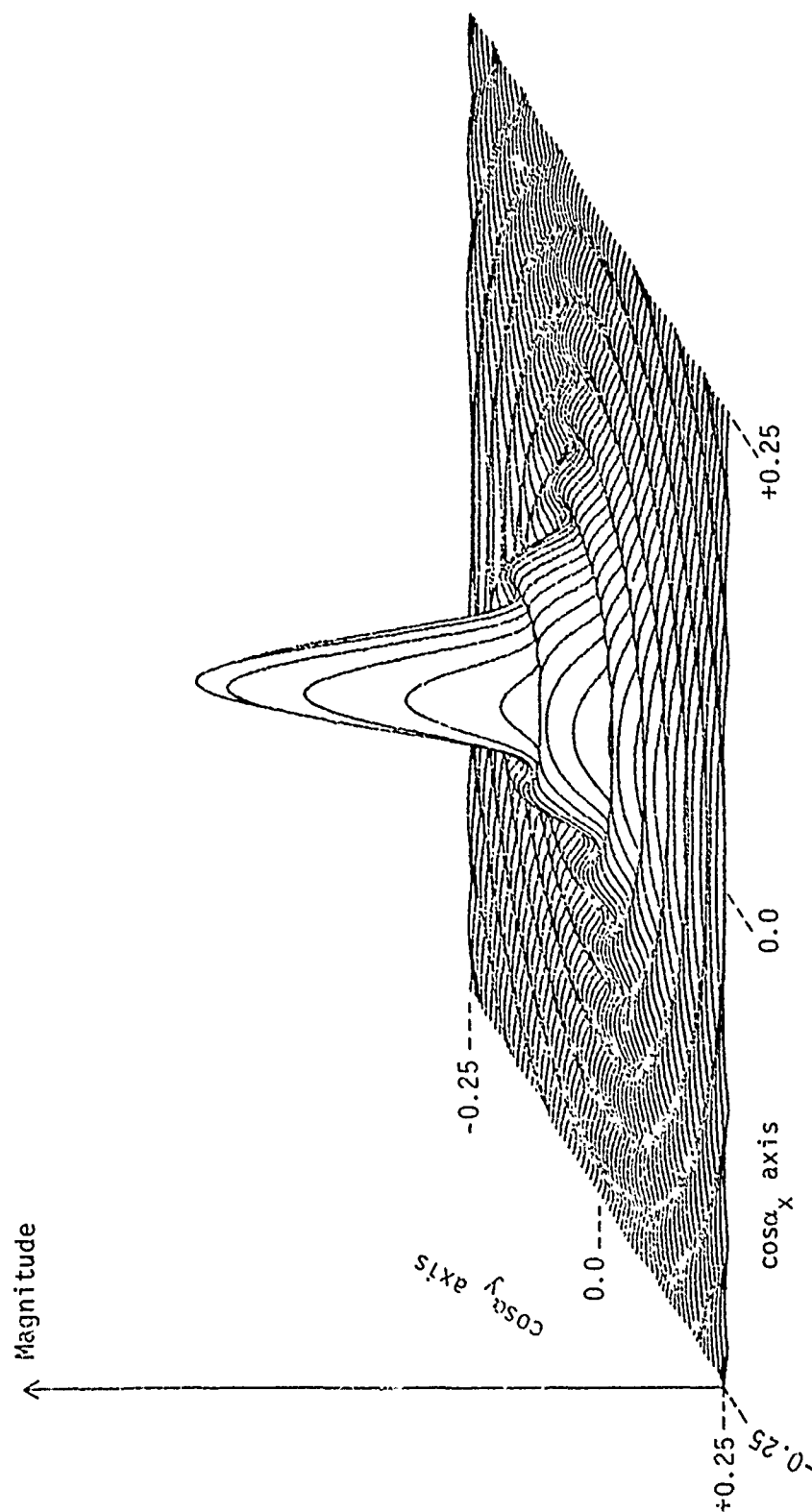


Figure 31. Far-field of uniform distribution with  $90.0^\circ$  of Bessel phase error at the center of the aperture (circular aperture  $w/\text{radius} = 32$ ).

a great extent by the number of radiating elements in the antenna. If the number of elements is reduced, then the cost of the installation is reduced accordingly. When the antenna pattern is modified by amplitude weighting, the number of elements is not changed but provisions for varying amounts of power to each element must be made. This means that either power is attenuated from a single transmitter or that various sizes of transmitters must be used. The price paid in the first case is a waste of power, in the second case, the price is a greatly complicated power generation and transmission system. If the required weighting to produce a good far-field were maintained with a reduction of radiating elements, the cost of the antenna could be maintained at a reasonable level. Additionally, if all of the elements were driven at a single power level, the complexity of the power generation and transmission system could be reduced. There would also be a much higher ratio of power transmitted to power radiated, thus, better efficiency and lower cost. These are all features of statistically loaded or space tapered arrays. The antenna array is loaded with only a few elements compared to the number required to completely fill the array. Each active element radiates unit power and the only losses are due to system losses, not to intentional attenuation. The elements are loaded into the array using the desired weighting function as a probability density function (20). Each element weight is compared to a random number generated from a uniform distribution. If the random number is less than or equal to the weight of the element, an active radiating element with unit power is placed at

that location. Otherwise, the location will be loaded with a non-radiating dummy element. When the array is completely loaded, the radiating elements are distributed according to the density function determined by the value of the weights of the design weighting function. An example of such an array is shown in Figure 32. This is a plot in dB where the symbols represent different dB levels. The "G" represents an element radiating at unit power. The weighting function used is a Taylor weighting with 20 dB design sidelobes and a value of 10 for  $\bar{N}$ . The amplitude weighting for this design is shown in Figure 18 for comparison. Notice that where there is a large amplitude in the weighting, there is a high density of elements in the thinned array. The far-field of the amplitude tapered array is shown in Figure 19 while the far-field of the thinned array is shown in Figure 33. The sidelobe level of the amplitude tapered array is 20 dB. The sidelobe level of the thinned array is at 18 dB in one spot, but the level of most of the sidelobes are as designed, 20 dB.

The major disadvantage of the thinning technique is not apparent in the 20 dB design. The mean sidelobe level of a purely random array is

$$SLL_R = 10 \log (1/N) \quad (3.13)$$

where N is the number of elements. In the design of the 20 dB Taylor array there are 1025 active elements which give a mean sidelobe level of 30 dB. Since the design was for 20 dB, the random sidelobe level did not effect the design to any great extent. If, however, the

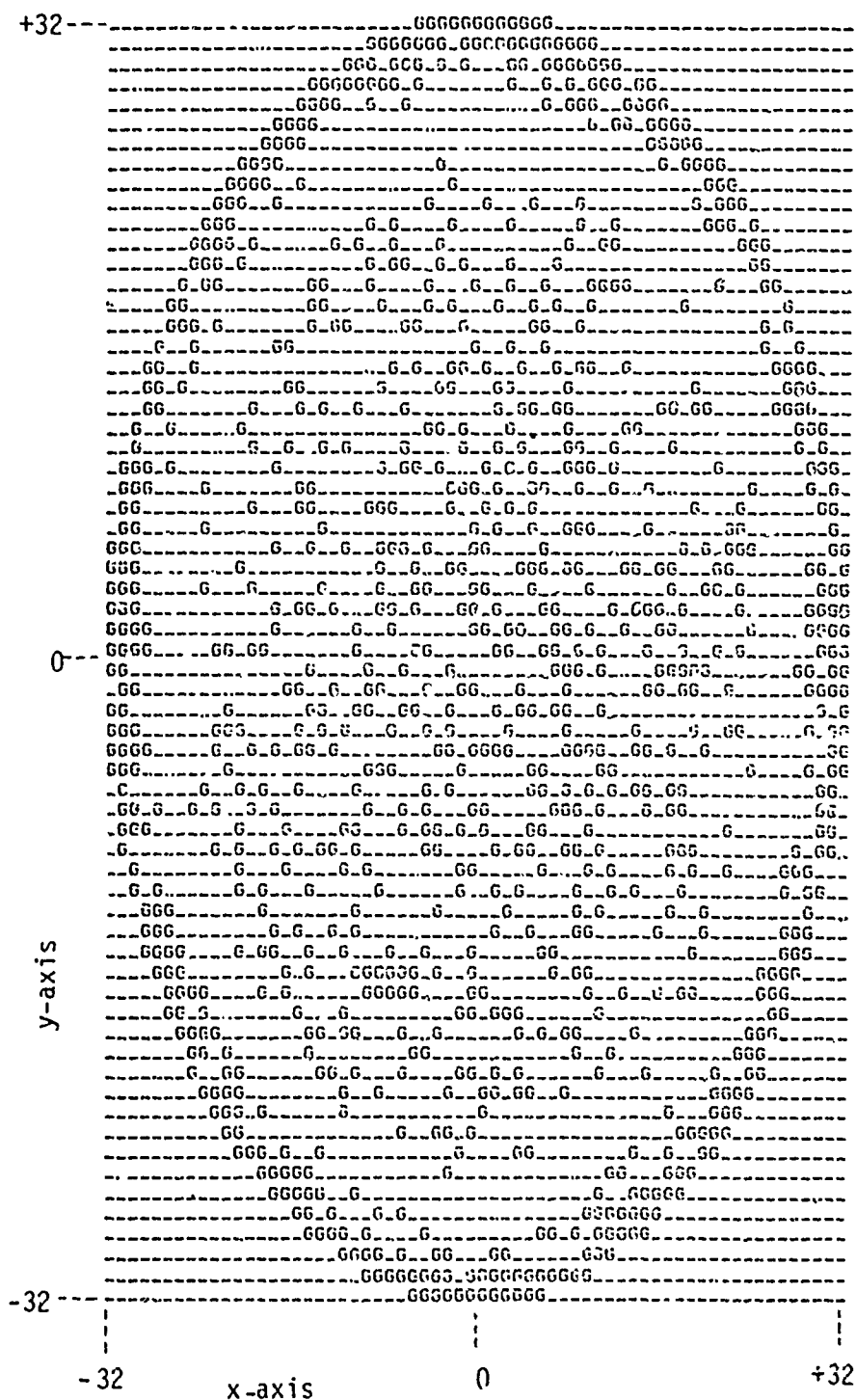


Figure 32. 20 dB statistically thinned Taylor aperture current distribution with  $N = 10$ .

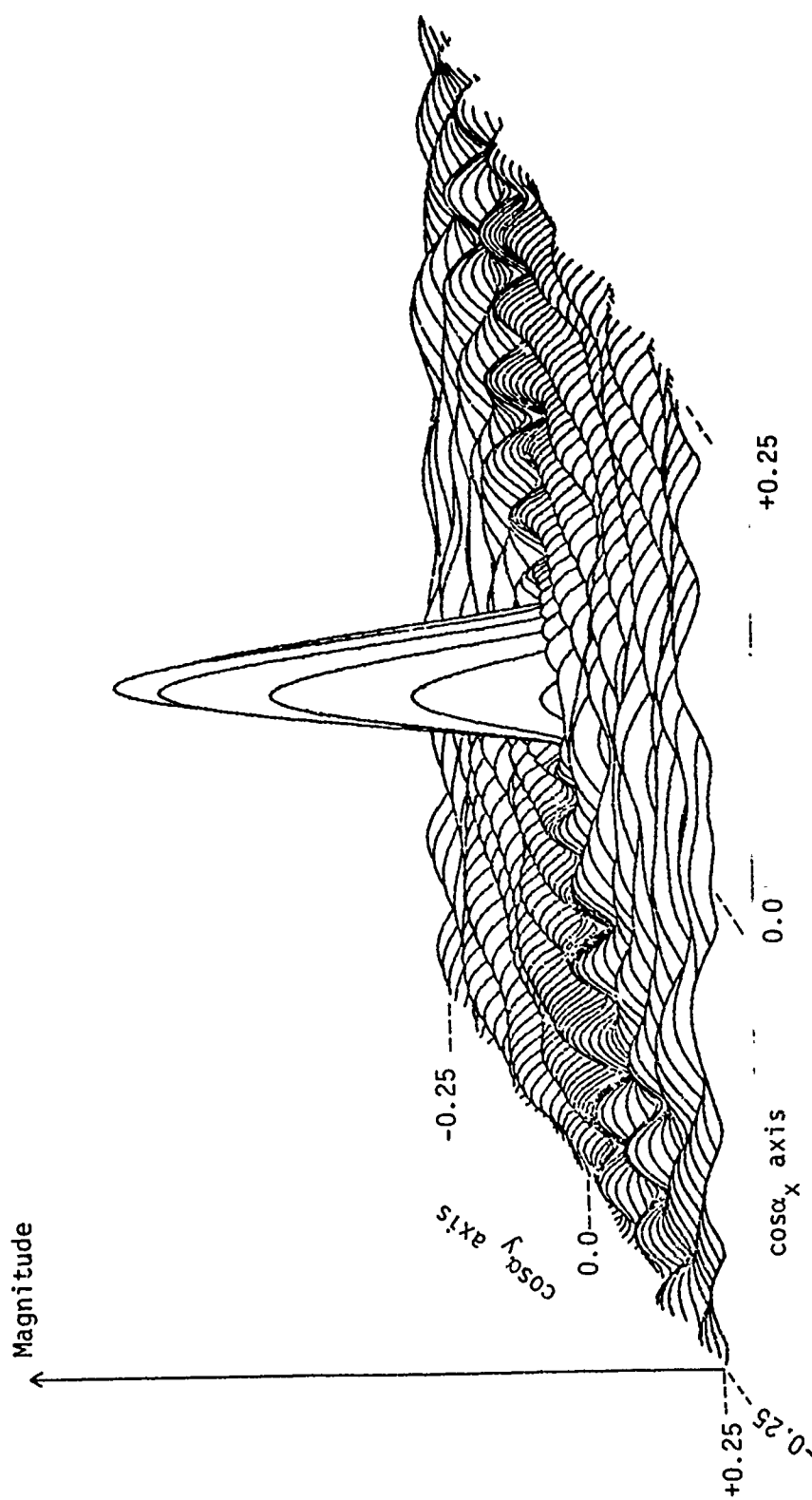


Figure 33. Far-field of statistically thinned Taylor distribution with  $\bar{N} = 10$ .

design had been for 35 dB sidelobes then the effects of the random sidelobe level would have caused severe deterioration in the far-field. Figure 34 illustrates the far-field of a 30 dB design. The aperture is loaded with 780 active elements which corresponds to a mean sidelobe level of 29 dB. Notice that the random sidelobe level dominates the far-field pattern except for the mainlobe. None of the design sidelobes are present.

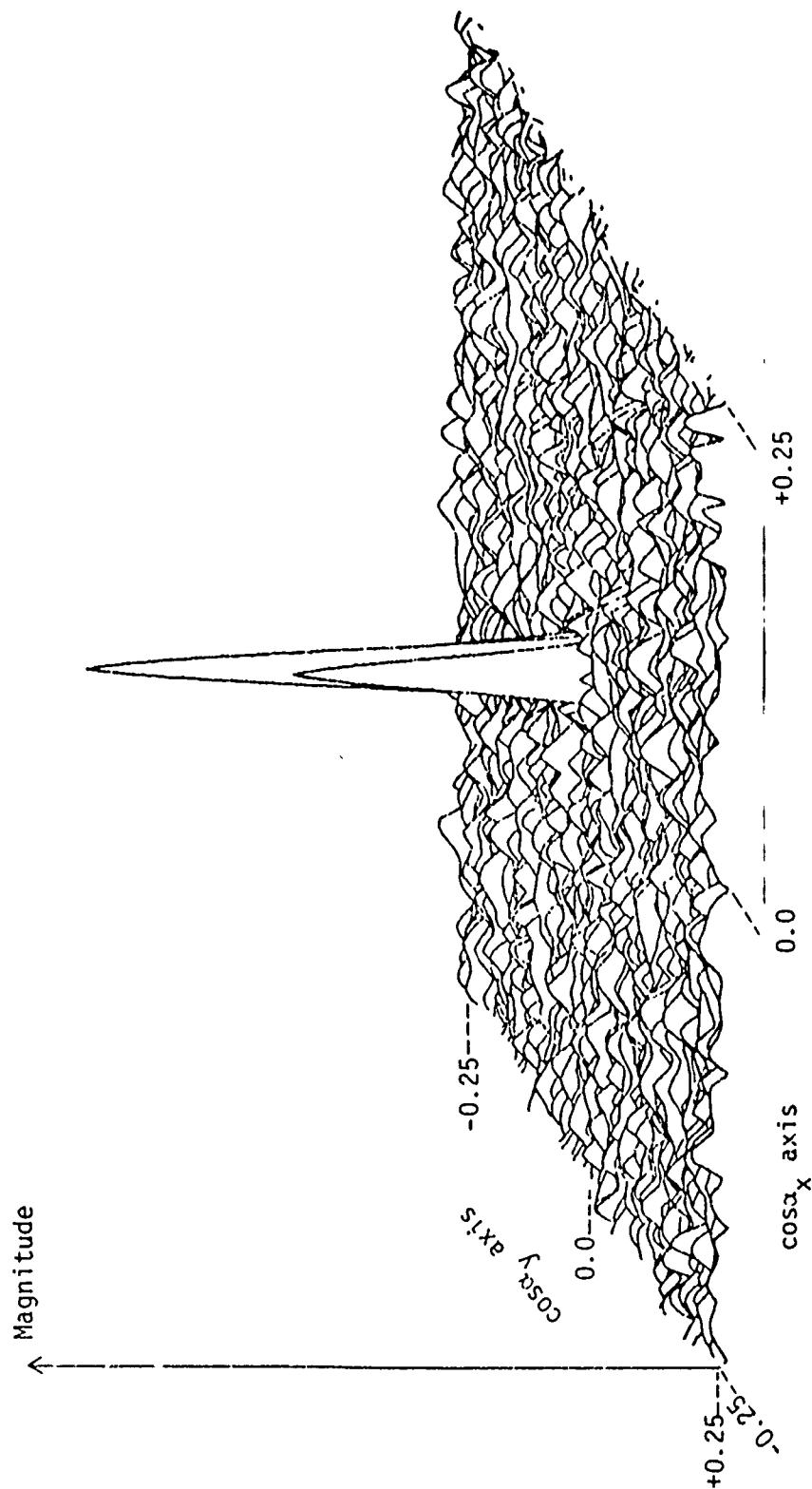


Figure 34. Far-field of 30 dB statistically thinned Taylor distribution with  $\bar{N} = 3$ , radius = 45, 780 active elements.

## CHAPTER IV

### RANDOM PHASE ERRORS, RNDERR

All of the antenna design work that has been discussed up to this point has neglected the effect of random phase errors. The aperture surface has been assumed to be perfectly smooth with no aberrations caused by structural errors or other surface defects. The transmission lines have been assumed to be all of perfect length so that every element radiates in perfect phase. In reality these assumptions are not accurate. The defects that arise in antenna systems can create severe degradation of the far-field. Some antenna designs that produce good radiation patterns only maintain this feature if random phase errors are ignored. The works of numerous authors are devoted to the effects of random phase errors on antenna patterns (13-19).

Random phase errors cause a redistribution of the radiated energy. Thus, the main beam suffers a loss in gain while the sidelobes receive the difference in gain as an increase in sidelobe level (13,17). If the increase caused by the random errors is small compared to the design sidelobe level, then the effects of the errors are not evident in the far-field. If on the other hand the sidelobe level of the design is below the error sidelobe level, the effects of the random errors are quite severe. An example of how the effects differ may be seen by the following comparison. The far-field of Figure 35 is the result of exactly the same aperture excitation as that of Figure 19



except that random phase errors have been added. The phase errors are chosen from a uniform distribution with a mean of  $0.0^\circ$  and a width of  $45.0^\circ$ . (At X-band this corresponds to a surface tolerance of plus or minus 1.9 mm with respect to the mean.) The effects of the errors in this example are not evident as a result of the low level of the random sidelobes compared to the design sidelobes.

Elliott gives the following three rules that characterize random phase errors in planar arrays (18).

- 1) The rise in the radiation sidelobes is more the lower the design sidelobe level, for a given antenna size and a given tolerance.
- 2) The rise in the radiation sidelobes is less the larger the antenna, for a given design sidelobe level.
- 3) The rise in sidelobe level due to random errors is independent of scan angle.

The first rule is illustrated by designing a 70 dB antenna of the same size and tolerance as the antenna which produced the far-field pattern in Figure 35. Figure 36 illustrates the far-field of a 70 dB design without phase errors. (The peak has been cut off so that the low sidelobes may be seen). The sidelobes are quite small and the regions away from the mainlobe are very well behaved. In Figure 37 the far-field of the same aperture is shown. The only difference is that phase errors (with the same distribution as above) have been added. The sidelobe level has come up from 70 dB to a level of 38 dB. The increase in the sidelobe level in this case resulted from

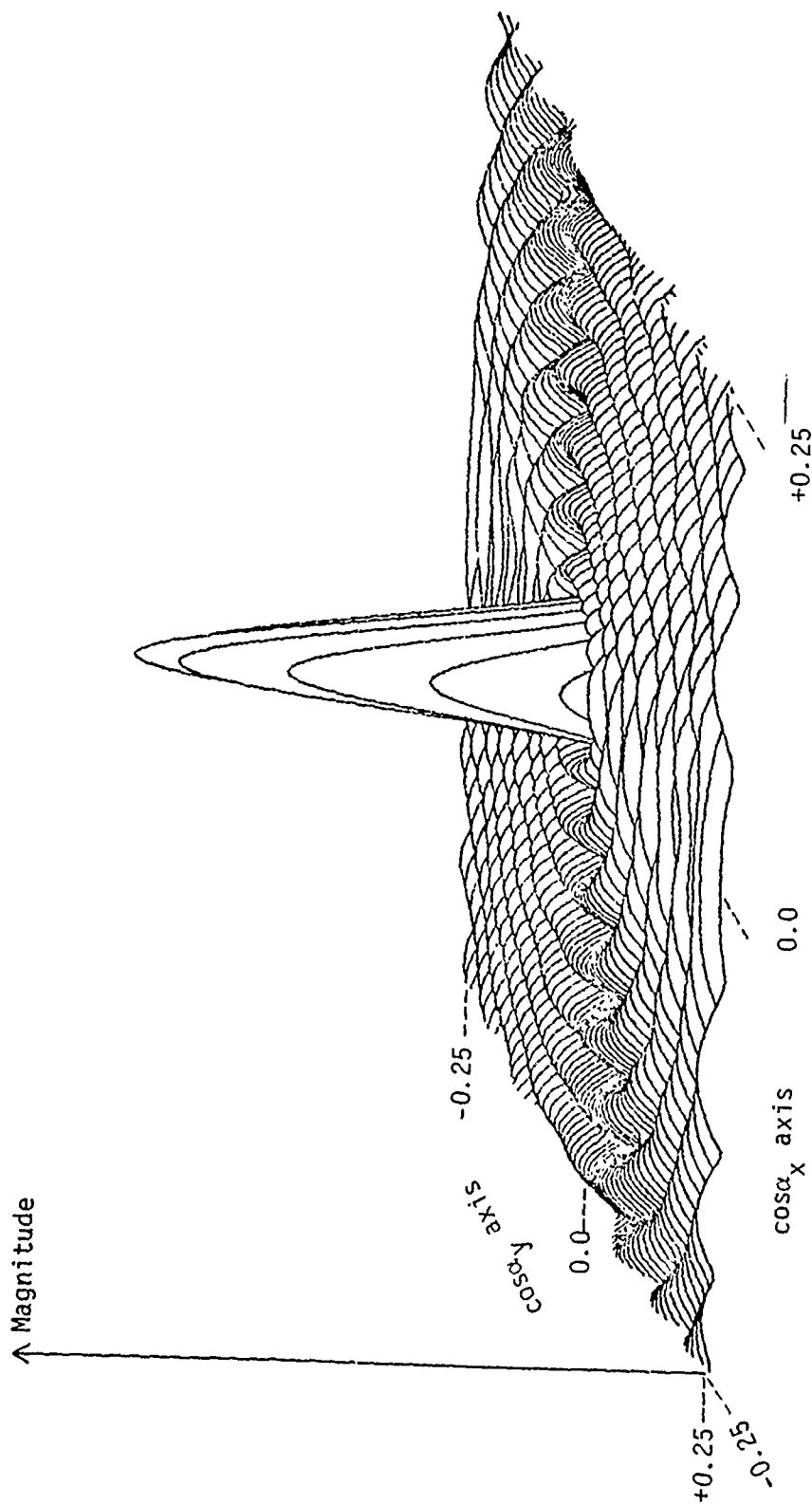


Figure 35. Far-field of 20 dB Taylor distribution with  $\bar{N} = 10$ , and uniform random phase error distribution with a mean of  $0.00^\circ$  and a width of  $45.00^\circ$ .

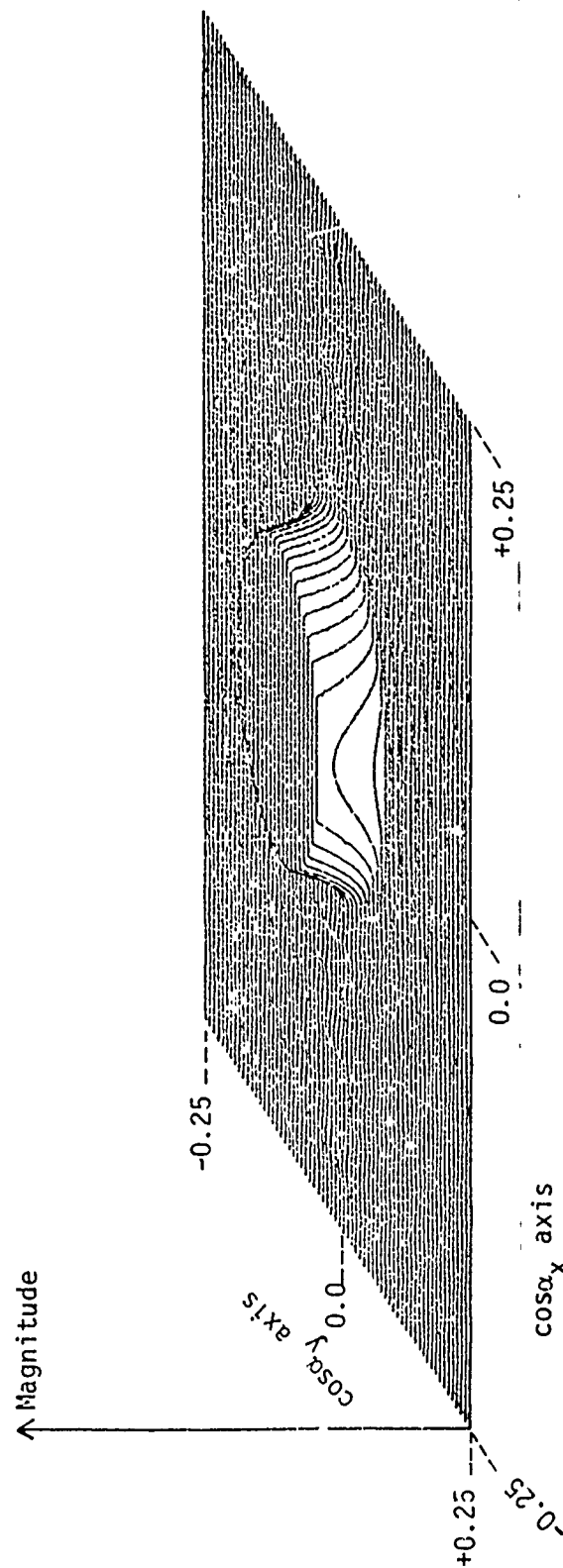


Figure 36. Far-field of 70 dB Taylor distribution with  $\bar{N} = 15$  and radius = 32.

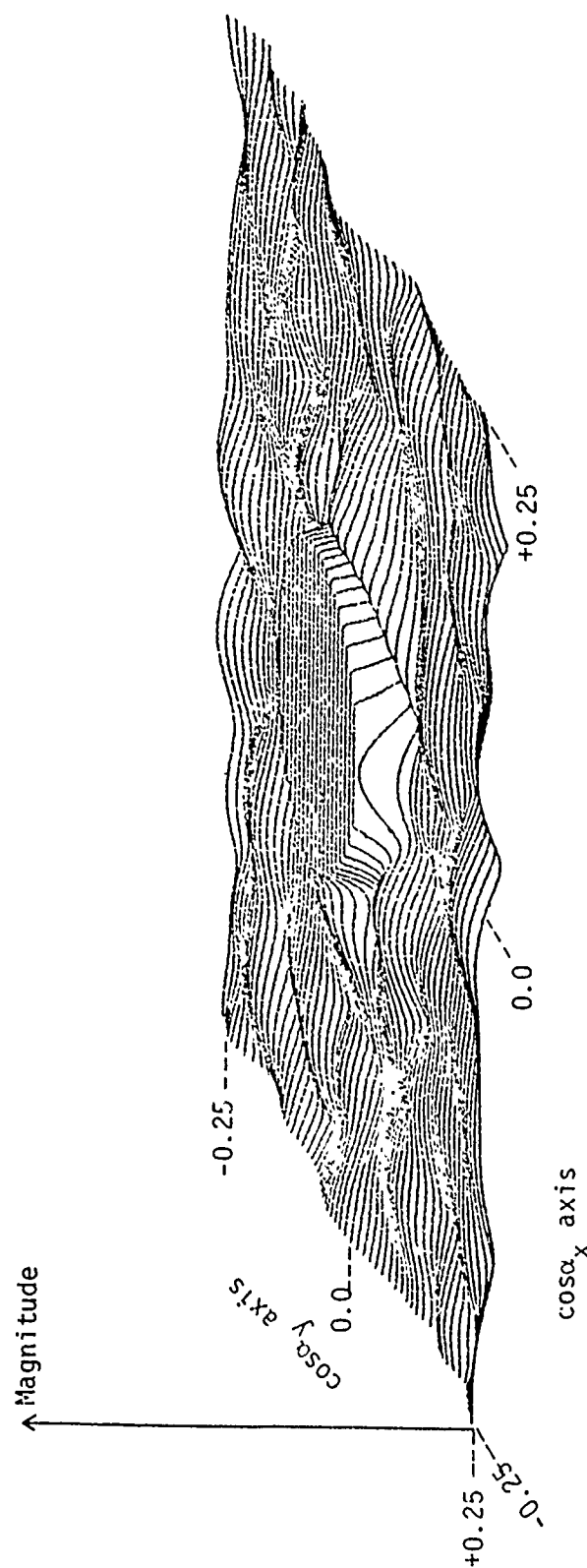


Figure 37. Far-field of 70 dB Taylor distribution with  $N = 15$ , radius =  $32.3^\circ$  and a uniform random phase error distribution with a mean of  $0.0^\circ$  and a width of  $45.0^\circ$ .

the fact that the random sidelobe level is much greater than the design sidelobe level.

Elliott's second rule is illustrated by doubling the radius of the aperture in the last example to 64 elements. The resulting far-field radiation pattern is shown in Figure 38. The peak sidelobe level in this case is down to 42 dB compared to 38 dB for the smaller aperture. The improvement in sidelobe level however is made at the enormous cost of increasing the number of elements from 3200 to 12,800 or a 400% increase in the number of elements.

Elliott's third rule states that the effects of random phase errors are independent of scan angle. To illustrate this the 70 dB array with random phase errors in Figure 35 is scanned to the orthogonal angles ( $21.09^\circ$ ,  $14.06^\circ$ ). Figure 39 illustrates the far-field pattern results. (20 bits of phase accuracy are used so that the effects of phase quantization are not present). The sidelobe level is still 38 dB as in Figure 37 but the beam has been moved to a different location. Notice also that the shape of the surrounding sidelobes has not changed from the far-field in Figure 37.

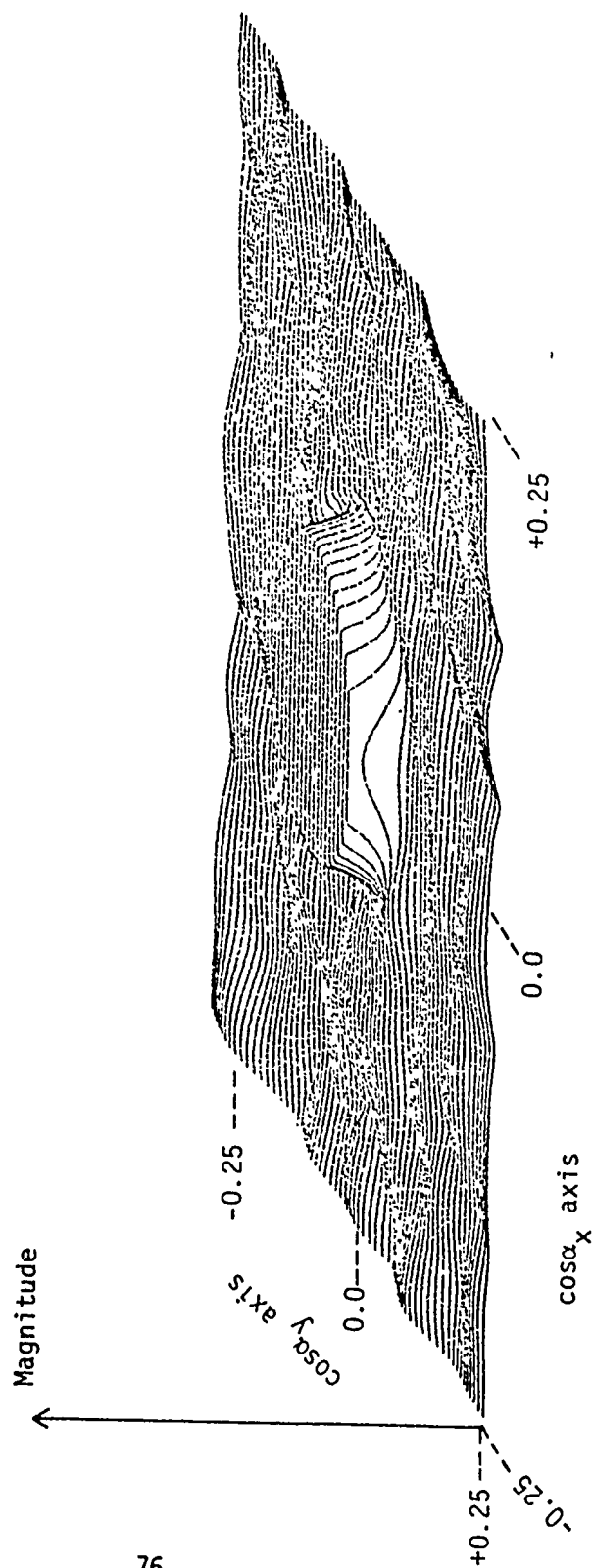


Figure 38. Far-field of 70 dB Taylor distribution with  $N = 15$ , radius =  $64.0^\circ$  and a uniform random phase error distribution with a mean of  $0.0^\circ$  and width of  $45.0^\circ$ .

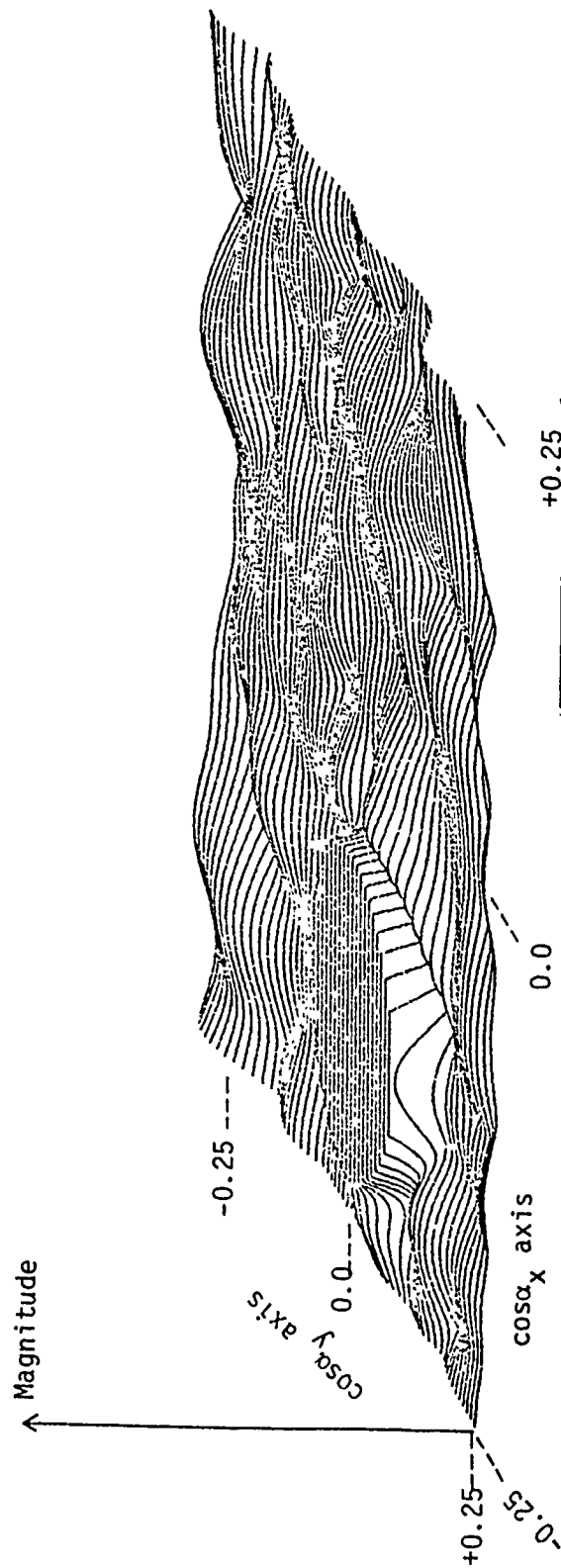


Figure 39. Far-field of 70 dB Taylor distribution with  $\bar{N} = 15$ , radius = 32, orthogonal beam steering angles (21.090, 14.060), and a uniform random phase error distribution with a mean of 0.00 and a width of 45.00.

## CHAPTER V

### APERTURE MODIFICATION, FILMOD

The apertures that have been discussed in the previous chapters have all been generated using closed form equations or random number generator schemes. In some antenna situations, notably mechanical dishes, there are obstructions in front of the illuminated aperture. These obstructions block the radiation of the illumination energy and cause deterioration of the far-field. Such obstructions include the feed and support on mechanically scanned dish antennas.

As an example a circular dish with a J-feed is modeled. The modified aperture is shown in Figure 40. The illumination function is assumed to be a uniformly weighted illumination. The dish reference plane has a radius of 32 samples and the center feed has a radius of 4 samples. The EM transmission line and support are 2 samples wide and run from the center to the edge of the aperture. The plot was done using the symbolic matrix representation because the shape of the hole and the support are easier to see than in the 3D-plots. The far-field of the modified aperture illumination is shown in Figure 41. Notice the difference between this figure and the far-field of the same aperture without the J-feed presented previously in Figure 6.

The effect of putting an obstruction in front of the aperture illumination is to remove the radiation from that part of the aperture. An analysis of this is now presented to evaluate the effect on both



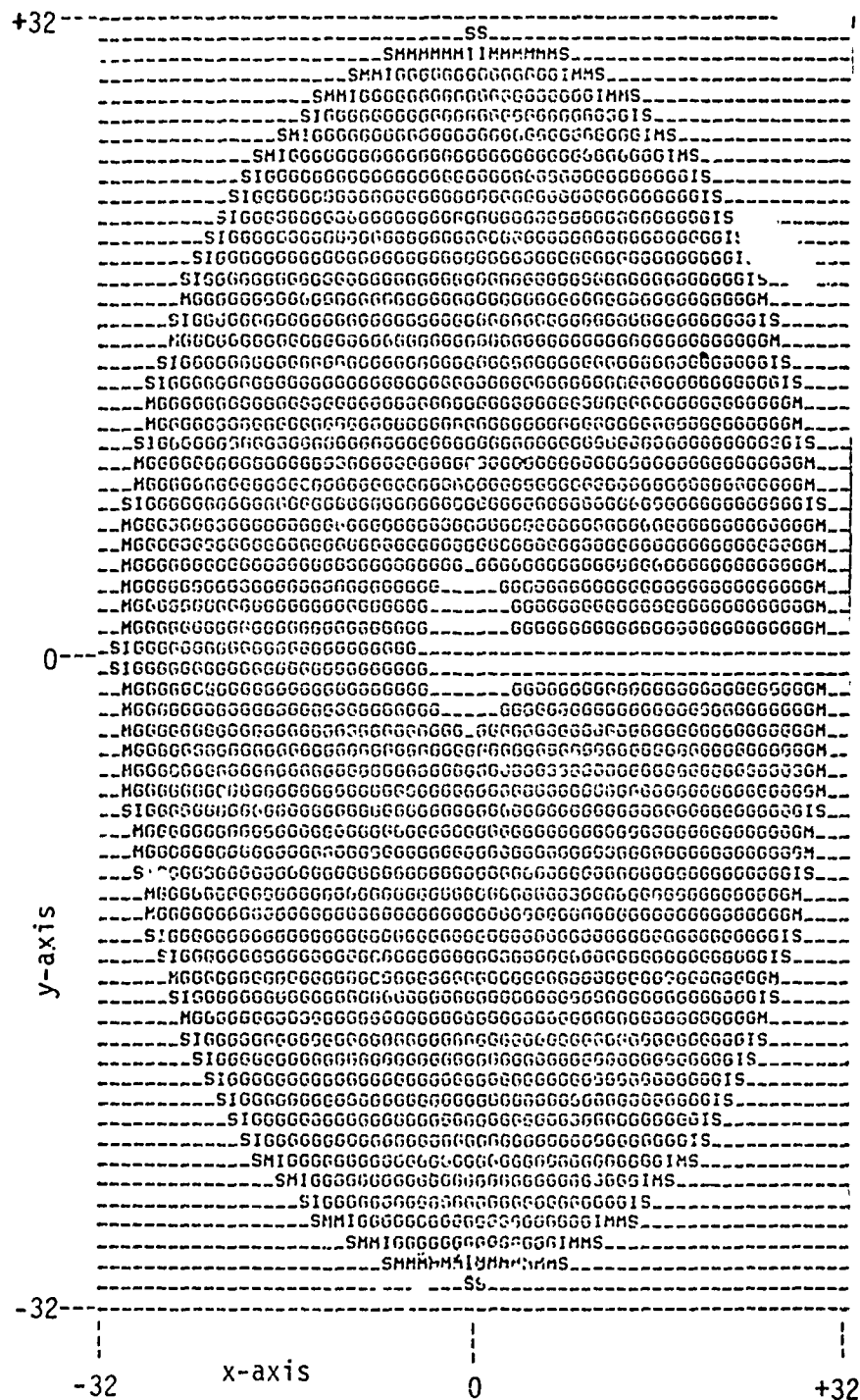


Figure 40. Uniform aperture current distribution with a radius of 32 samples and a J-feed. Feed radius of 4 samples and EM transmission line width of 2 samples.

the complex E-field pattern and the power pattern.

Let  $X(k)$  be the original illumination function with no aperture blockage and let  $Y(k)$  be an illumination function in the shape of the blocked radiation. From the work presented in Chapter II it is known that the far-field of any planar aperture illumination function is the inverse discrete Fourier transform of that illumination function. Thus, the far-field of  $X(k)$  and  $Y(k)$  are the following:

$$x(n) = \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} kn} \quad (5.1)$$

$$y(n) = \sum_{k=0}^{N-1} Y(k) e^{j \frac{2\pi}{N} kn} \quad (5.2)$$

The far-field of the difference of  $X(k)$  and  $Y(k)$ ,  $Z(k)$  is then

$$Z(k) = X(k) - Y(k) \quad (5.3)$$

where

$$z(n) = \sum_{k=0}^{N-1} Z(k) e^{j \frac{2\pi}{N} kn} \quad (5.4)$$

$$= \sum_{k=0}^{N-1} (X(k) - Y(k)) e^{j \frac{2\pi}{N} kn} \quad (5.5)$$

$$= \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} kn} - \sum_{k=0}^{N-1} Y(k) e^{j \frac{2\pi}{N} kn} \quad (5.6)$$

$$z(n) = x(n) - y(n) \quad (5.7)$$

Therefore, the E-field radiation of the difference of two illumination functions is the difference of the respective radiation patterns. This

result however only applies to the complex E-field radiation pattern. For the power far-field the magnitude squared of  $Z(n)$  must be found as

$$|z(n)e^{j\phi_3(n)}|^2 = |x(n)e^{j\phi_1(n)} - y(n)e^{j\phi_2(n)}|^2 \quad (5.8)$$

$$= |x(n)|^2 e^{j2\phi_1(n)} - 2|x(n)|e^{j\phi_1(n)}|y(n)|e^{j\phi_2(n)} + |y(n)|^2 e^{j2\phi_2(n)} \quad (5.9)$$

$$= \{|x(n)|^2 - 2|x(n)||y(n)| + |y(n)|^2\} @ \angle f(\phi_1(n), \phi_2(n)) \quad (5.10)$$

It is clear now that the magnitude plots shown in Figure 43 and Figure 6 do not have a simple linear difference relationship between them.

For the case of a uniform distribution with a J-feed, the far-field,  $x(n)$ , is shown in Figure 41. The portion of the aperture illumination removed as a result of the J-feed,  $Y(k)$ , is shown in Figure 42 and its corresponding far-field,  $y(n)$ , is shown in Figure 43. Upon comparing the plots of Figure 43 and Figure 41 in light of the above derivation, it may now be seen why there is an increase in the sidelobe level along the x-axis of the plot in Figure 41 rather than a decrease. In Figure 44 a far-field plot is shown of an illumination with exactly the same parameter as in the above example except that the weighting has a triangular distribution. Notice that the triangular weighting has greatly decreased the sidelobe amplitude structure of the far-field although the effects of the J-feed

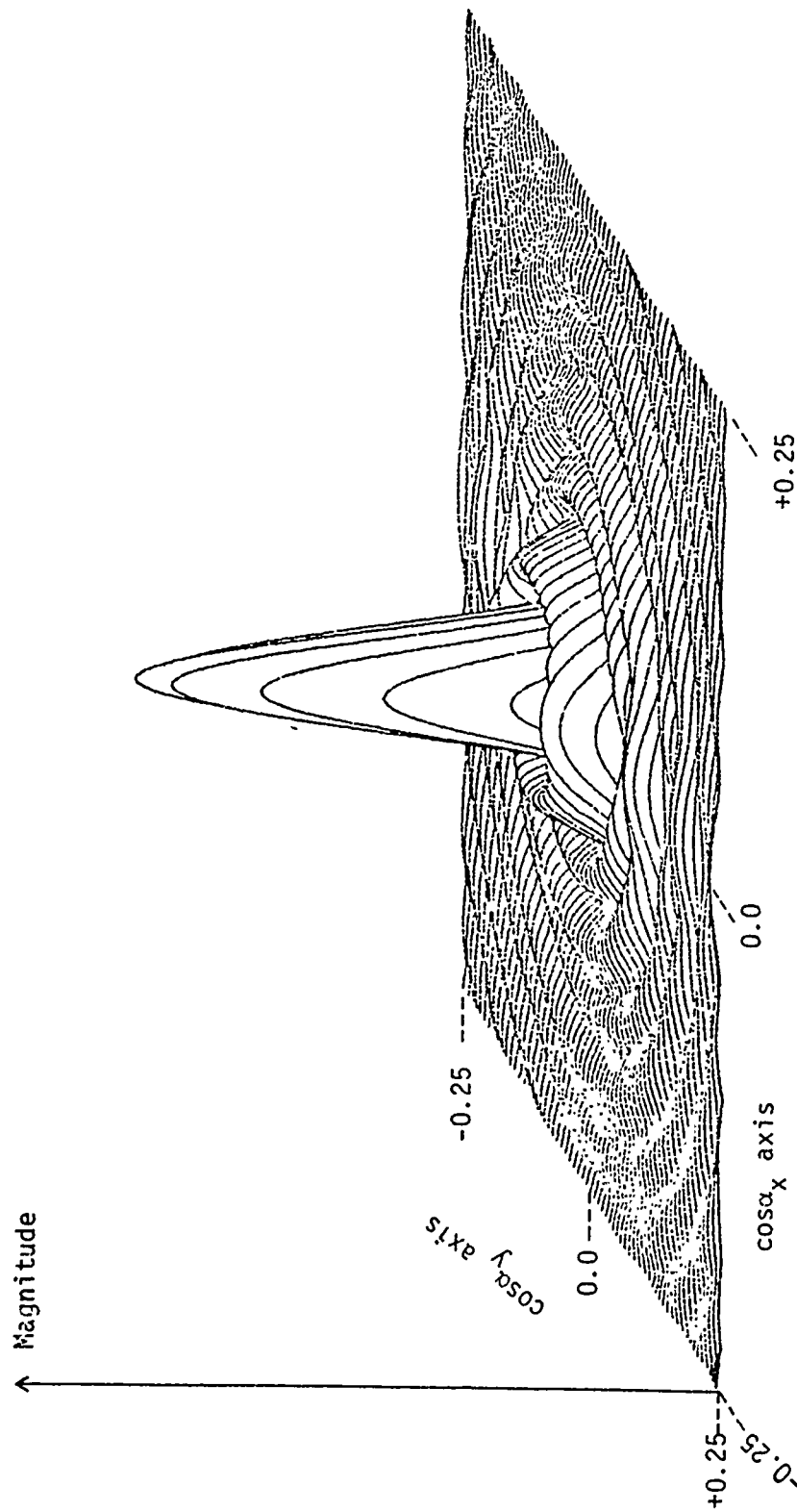


Figure 41. Far-field of uniform distribution with J-feed shown in Figure 40.

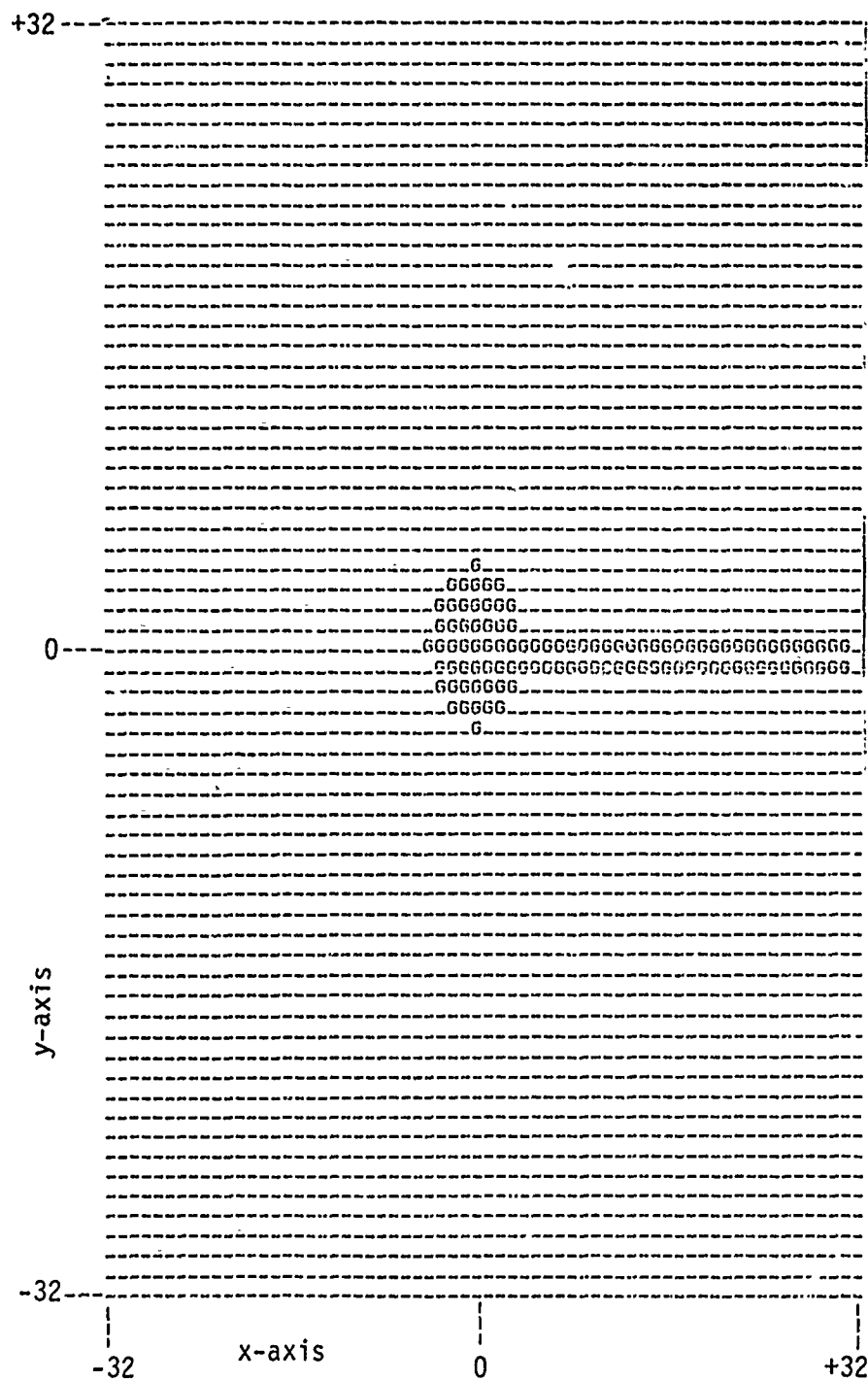


Figure 42. Uniform aperture current distribution in shape of J-feed that was removed from the distribution in Figure 40.

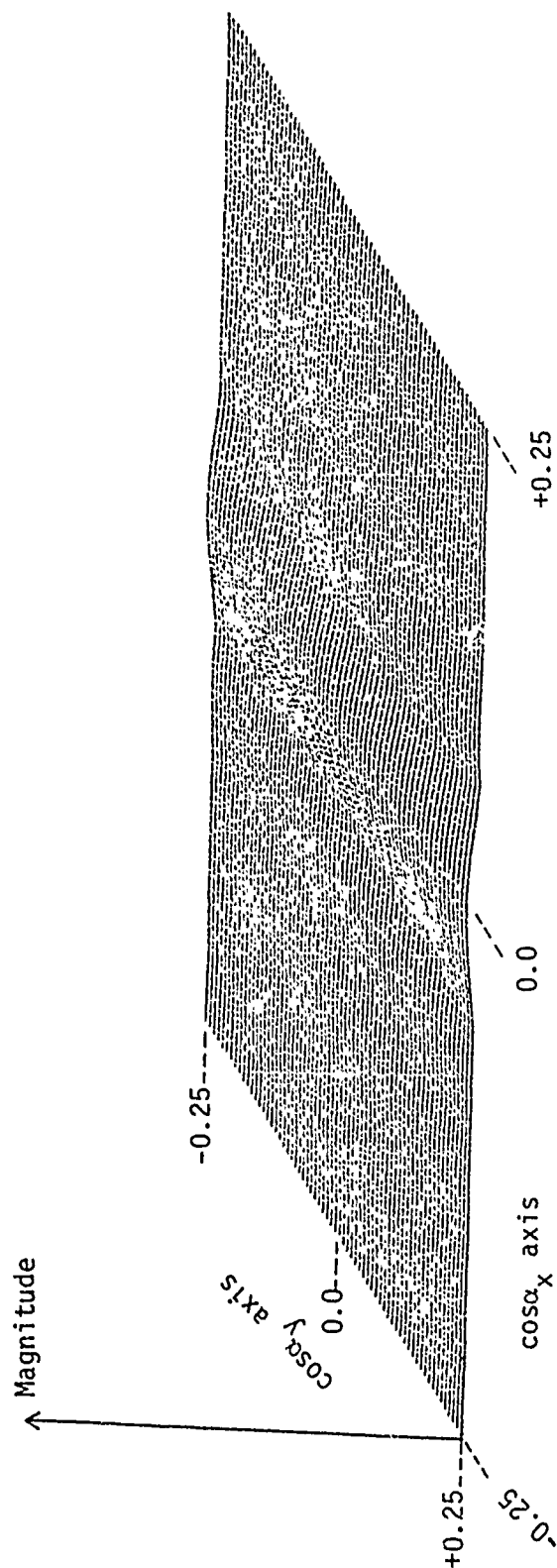


Figure 43. Far-field of uniform distribution in shape of J-feed shown in Figure 42.

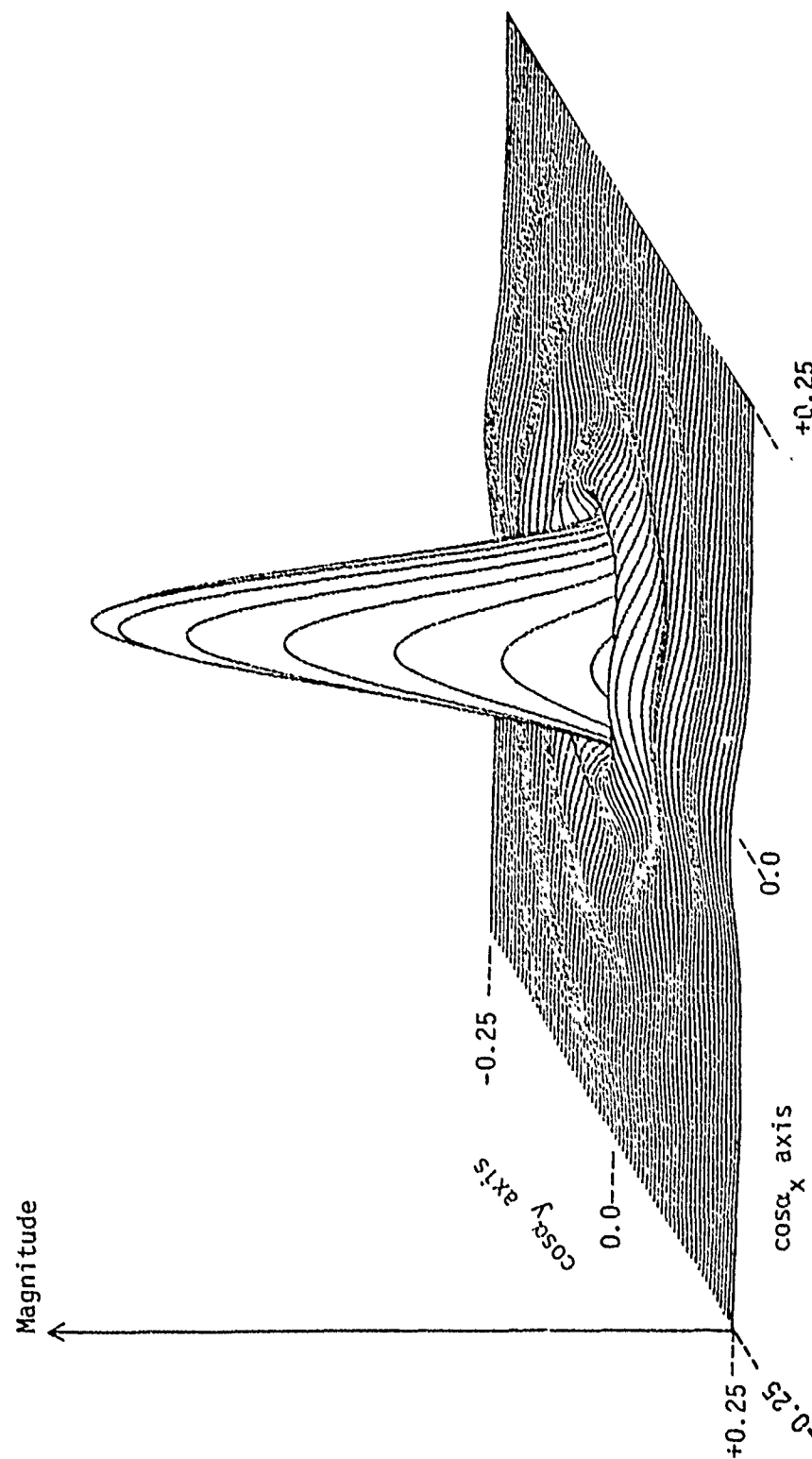


Figure 44. Far-field of triangular distribution with J-feed.

obstruction are still quite evident.

Other antenna effects can also be modeled using the module. These include transmitter failure, burned out radiators, or broken transmission lines and other radiation blocking phenomenon.

Sensitivity experiments could be carried out by the designer to determine the best place to position the feeds and supports so that the far-field degradation is minimized.



## CHAPTER VI

### CONCLUSION

With the set of PAAS modules presented herein, the antenna designer may model a wide variety of antenna situations. Provision for shape, size, weighting, deterministic phase errors, random phase errors, beam steering, and statistical loading are included in PAAS. Through the use of PAAS the designer may study in detail the effects on the radiation pattern caused by various antenna aperture parameters. The radiation patterns are generated quickly and may be studied in two different forms, or the designer may wish to process the data in some other manner. The versatility and speed of the simulation presents no programming problem for the user since each antenna design is implemented using the same set of modules with the same question and answer sequences. There is no need for a new program when each new antenna design is encountered.

For future research, features that are not included in this simulation but may prove to be useful are:

- 1) Random amplitude errors,
- 2) Random element position errors,
- 3) Correlated phase errors and,
- 4) The effects of mutual coupling.

Random amplitude errors arise because not all elements in the array have the same gain characteristics. Random element position errors

occur because of the inaccuracy of the structural placement of the elements in the array grid. Random position errors can have disastrous effects on the radiation pattern of phased array antennas (18). Correlated phase errors are due to structural deformations. If a certain radiator is very high above the aperture plane, surrounding radiators will probably be above the aperture also. This results from the fact that the antenna surface is relatively smooth but non-planar. There are hills and valleys in which the radiators can be placed and thus areas of correlated error result. The radius of correlation of the phase error is very important (14). The effects of mutual coupling in phased array antennas is perhaps the most difficult problem to work with (26). It is also the most difficult to stimulate accurately. If in some relatively simple way the effects of mutual coupling could be added to PAAS, the far-field results would be more accurate and therefore of more use to the antenna designer.

With these additions PAAS could become a very powerful tool for an extremely wide variety of antenna configurations. In minutes the designer can now gain information about the far-field radiation pattern which would take much longer using present antenna analysis techniques.

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## A P P E N D I X 1

### FIGURE/COMPUTER RUN CROSS REFERENCE

In this appendix, Table A1-1 is presented which provides a list of the input parameters that were used in generating the figures presented in the body of this report.

Unless stated otherwise, all of the far-field radiation patterns were calculated using the following FFT2DX parameter values.

N2-8  
LRJ-LRK-4  
LRJIN-LRKIN-6  
LRJWID-LRKWID-4

Unless stated otherwise, the following H3DPL parameter values were used in producing all of the 3-D plots.

IXFAC-15  
IYFAC-11  
LFLAC-0  
TL-0.0  
IPAD-4  
IXST-500  
IXRNC-2300  
IYBOT-700  
IYRNG-1500  
ICFLC-0

The value used for TH in plotting the aperture distributions was approximately 3.0 times the peak value of the aperture distribution. Usually peak equals 1.0. The value used for TH in plotting the far-field patterns was approximately 1.5 times the peak value of the far-field magnitude.

The programs called and pertinent parameter values are now given in the following table for each of the PAAS jobs run to produce data presented in this report. In this table the figure numbers are the same as those assigned in the body of the report.

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
1	5	PLARY	IAPTFL-3 NWIDTH-40 NHIGH-40 IWTFLC-0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	1600
2	6	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLC-0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	3200
3	7,8	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLC-1 WTRAD-32.0 WTPED-0.0 NWTPOW-1 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	1300

Table A1-1 Figure/ Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
4	10,11	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLG-2 WTRAD-30.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	650
5	12,13	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLG-3 WTRAD-30.0 WKASIR-2.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	2000
6	14,15	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLG-3 WTRAD-30.0 WKASIR-8.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	650



Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
7	16,17	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLC-4 WTRAD-30.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	1000
8	18,19	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLC-5 WTRAD-32.0 DB-20.0 NBAR-10 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	650
9	20,21	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLC-6 WTRAD-30.0 BESCAL-1.0 BESEDC-0.08 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	1300

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
10	22,23	PLARY	IAPTFL-3 NWIDTH-40 NHIGH-40 IWTFLG-7 ZJRAD-20.0 ZKRAD-20.0 CUBK-1.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	800
11	24,25	PLARY	IAPTFL-1 KEDGE-32.0 KHOLE-0.0 IWTFLG-8 WTRAD-32.0 DB-20.0 NBAR-10 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	250
12	27	PLARY	IAPTFL-1 KEDGE-32.0 KHOLE-0.0 IWTFLG-0 DELPHJ-22.0 DELPHK-15.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	3200

Table A1-1 Figure/Computer Run Cross Reference

Table				
RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
13	28	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLC-0 DELPHJ-22.0 DELPHK-15.0 NBITS-3 LRJ-LRK-4	
		FFT2DX	-	3200
14	29	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLC-5 WTRAD-32.0 DB-70.0 NBAR-15 DELPHJ-22.0 DELPHK-15.0 NBITS-3 LRJ-LRK-4	
		FFT2DX	N2-7 LRJ-LRK-4 LRJIN-LRKIN-0 LRJWID-LRKWID-8	650

16 JUN 77

Table A1-1 Figure/Computer Run Cross Reference

## Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
15	30	PLARY	IAPTFL-3 NWIDTH-40 NHIGH-40 IWTFLG-0 PHERX-90.0 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	1600
16	31	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLG-0 NBITS-20 BESERR-90.0 BSCAL-0.08 LRJ-LRK-4	
		FFT2DX	-	3200
17	32,33	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLG-5 WTRAD-32.0 DB-20.0 NBAR-10 NBITS-20 XKK-1.0 MAD1-JRND-1 LRJ-LRK-4	
		FFT2DX	-	900

16 JUN 77

Table A1-1 Figure/Computer Run Cross Reference

Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
18	34	PLARY	IAPTFL=1 XEDGE=45.0 XHOLE=0.0 IWTFLG=5 WTRAD=45.0 DB=30.0 NBAR=3 NBITS=20 XKK=0.24 MAD1-JRND=1 LRJ-LRK=6	
		FFT2DX	LRJ-LRK=6	750
19	35	PLARY	IAPTFL=1 XEDGE=32.0 XHOLE=0.0 IWTFLG=5 WTRAD=32.0 DB=20.0 NBAR=10 NBITS=20 LRJ-LRK=4	
		RNDERR	NTYPE=1 MAD1-JRND=1 LRJ-LRK=4 UMEAN=1.0 UUEXT=45.0	
		FFT2DX	-	650

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
20	36	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLG-5 WTRAD-32.0 DB-70.0 NBAR-15 NBITS-20 LRJ-LRK-4	
		FFT2DX	-	650

NOTE: To produce Figure 36, the peak value, TH, is set to 100.0 and the data is clipped at 10.0 in the plotting program H3DPL.

21	37	PLARY	IAPTFL-1 XEDGE-32.0 XHOLE-0.0 IWTFLG-5 WTRAD-32.0 DB-70.0 NBAR-15 NBITS-20 LRJ-LRK-4	
		RNDERR	NTYPE-1 MAD1-JRND-1 LRJ-LRK-4 UNEAN-0.0 UUEXT-45.0	

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
		FFT2DX	-	650
NOTE: To produce Figure 37, use the same procedure as for Figure 36 in Run # 20.				
22	38	PLARY	IAPTF1-1 XEDGE-64.0 XHOLE-0.0 IWTFLC-5 WTRAD-64.0 DB-70.0 NBAR-15 NBITS-20 LRJ-LRK-8	
		RNDERR	NTYPE-1 MAD1-JRND-1 LRJ-LRK-8 UMEAN-0.0 UUEXT-45.0	
		FFT2DX	LRJ-LRK-8	2500

NOTE: To produce Figure 38, the peak value, TH, is set to 400.0 and the data is clipped at 40.0 in the plotting program H3DPL.

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
23	39	PLARY	IAPTFL-1 XEDGE=32.0 XHOLE=0.0 IWTFLG=5 WTRAD=32.0 DB=70.0 NBAR=15 DELPHJ=21.09 DELPHK=14.06 NBITS=20 LRJ-LRK=4	
		RNDERR	NTYPE=1 MAD1-JRND=1 LRJ-LRK=4 UMEAN=0.0 UUEXT=45.0	
		FFT2DX	-	650
NOTE: To produce Figure 39, use the same procedure as for Figure 36 in Run # 20.				
24	41	PLARY	IAPTFL-1 XEDGE=30.0 XHOLE=0.0 IWTFLG=0 NBITS=20 LRJ-LRK=4	



Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
		FILMOD	LRJ-LRK-4 ICNTJ-ICNTK-32 KHOLE-3 Set the following elements to (0.0,0.0) Block 7: (1,16)-(16,16) Block 8: (1,16)-(16,16) Block 11: (1,1)-(16,1) Block 12: (1,1)-(16,1)	
		FFT2DX	-	3100
25	43	PLARY	IAPTF1-1 KHEDGE-1.0 KHOLE-2.0 IWTFLC-0 NBITS-20 LRJ-LRK-4	
		FILMOD	LRJ-LRK-4 Set the following elements to (1.0,0.0) Block 6: (12,16), (13,14)-(13,16), (14,13)-(14,16), (15,13)-(15,16), (16,12)-(16,16)	

Table A1-1 Figure/Computer Run Cross Reference  
Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
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Block 7:  
(13,1)-(13,2),  
(14,1)-(14,3),  
(15,1)-(15,3),  
(16,1)-(16,16)

Block 8:  
(16,1)-(16,15)

Block 10:  
(1,13)-(1,16),  
(2,13)-(2,16),  
(3,14)-(3,16),  
(4,16)

Block 11:  
(1,1)-(1,16),  
(2,1)-(2,3),  
(3,1)-(3,2),  
(4,1)

Block 12:  
(1,1)-(1,15)

FFT2DX	-	100
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NOTE: To produce Figure 43, the peak value, TH, used in the plotting program H3DPL should be 3100.

26	44	PLARY	IAPTFL-1 XEDGE-30.0 XHOLE-0.0 IWTFLC-4 WTRAD-30.0 NBITS-20 LRJ-LRK-4
----	----	-------	--

Table A1-1 Figure/Computer Run Cross Reference

Table

RUN #	FIG #	PROGRAMS CALLED	PROGRAM PARAMETER VALUES	FAR-FIELD PEAK VALUE
		FILMOD	LRJ-LRK-4 ICNTJ-ICNTK-32 XHOLE-3 See Note	
		FFT2DK	-	800

NOTE: Use the same procedure for  
the zero elements as in  
Run # 24.

## A P P E N D I X 2

### TAYLOR WEIGHTING FUNCTION TABLES

In this appendix a table is presented of the Taylor weighting function for a circular antenna aperture. This table is similar to that published by Hansen<sup>10</sup>, but is more accurate and has greater range in the design side lobe level and  $\bar{N}$ .

In this table the design side lobe level is shown as the parameter, DB. The parameter A is derived from DB by using the following expression:

$$A = 1/\pi \cosh^{-1}[10.0^{DB/20}]$$

For each value of NBAR, the beam spread factor, SIGMA, and the associated sampled weighting function are tabulated. In this table 20 samples were taken across the radius of the aperture. The number of samples is user defined and can be changed to give either finer or more coarse sampling. In preparing this table the values of  $\bar{N}$  which were not allowable were omitted. The minimum allowable value of  $\bar{N}$  is a function of the design side lobe level.

DB=20

A= 0.95277244

NBAR= 3

4

5

6

7

SIGMA=

	1.21040334	1.16918564	1.13979128	1.11859846	1.10279417
0	0.30586821	0.24997965	0.27908092	0.22803256	0.26390182
1	0.30399587	0.25145539	0.27499860	0.23230423	0.25689566
2	0.29851499	0.25528986	0.26429914	0.24198823	0.24142572
3	0.28982119	0.25985867	0.25092540	0.24980502	0.22905596
4	0.27853267	0.26293043	0.23942150	0.24925486	0.22681846
5	0.26543292	0.26225955	0.23283092	0.23904646	0.23099148
6	0.25139897	0.25620375	0.23122267	0.22398464	0.23106187
7	0.23732269	0.24421544	0.23153281	0.21158377	0.22024444
8	0.22403286	0.22708495	0.22885999	0.20655472	0.20254156
9	0.21222626	0.20687100	0.21873043	0.20689399	0.18912374
10	0.20241405	0.18652707	0.19940814	0.20449357	0.18668586
11	0.19488885	0.16930374	0.17325740	0.19039345	0.18863193
12	0.18971500	0.15806019	0.14650480	0.16170804	0.17866847
13	0.18674228	0.15464030	0.12736859	0.12583130	0.14590296
14	0.18564094	0.15945525	0.12318067	0.09876968	0.09946395
15	0.18595314	0.17136832	0.13755728	0.09776239	0.06888296
16	0.18715508	0.18790927	0.16870329	0.13182583	0.08660317
17	0.18872220	0.20577204	0.20954233	0.19541935	0.16355521
18	0.19019055	0.22148614	0.24969899	0.26905656	0.27595986
19	0.19120730	0.23211478	0.27867377	0.32706119	0.37486015
20	0.19156544	0.23582888	0.28910934	0.34879742	0.41374269

NBAR= 8

9

10

11

12

SIGMA=

	1.09062086	1.08098233	1.07317345	1.06672445	1.06131157
0	0.21625671	0.25484496	0.20902105	0.24891050	0.20415076
1	0.22386643	0.24436474	0.22035731	0.23464818	0.21936695
2	0.23779304	0.22624200	0.23557145	0.21718538	0.23224837
3	0.24180135	0.22116838	0.23067540	0.22186019	0.21885013
4	0.23118257	0.22804089	0.21608411	0.22686374	0.21240452
5	0.21739223	0.22790120	0.21428625	0.21371480	0.21901977
6	0.21306872	0.21392953	0.21869050	0.20425888	0.20928515
7	0.21600606	0.20117350	0.20895276	0.20835986	0.19592684
8	0.21227930	0.20112441	0.19191162	0.20141830	0.19916262
9	0.19518807	0.20158257	0.18866009	0.18222165	0.19189144
10	0.17593030	0.18584196	0.19083628	0.17851092	0.17118966
11	0.17022413	0.16289780	0.17367213	0.18069239	0.17102989
12	0.17489409	0.15703127	0.14837537	0.15741156	0.16892024
13	0.16477822	0.16449076	0.14818525	0.13419130	0.13600895
14	0.12071230	0.14485297	0.15477588	0.14590770	0.12795436
15	0.06216907	0.07785381	0.10566747	0.13087671	0.14161057
16	0.04530559	0.01886615	0.01336689	0.02830181	0.05708473
17	0.11784653	0.06489219	0.01264940	-0.03107530	-0.06005262
18	0.26832392	0.24546254	0.20803753	0.15795745	0.09819321
19	0.42015689	0.46129559	0.49680535	0.52538435	0.54590590
20	0.48330312	0.55706118	0.63471540	0.71603205	0.80082592

NBAR=	13	14	15	16	17
SIGMA=	1.05670533	1.05273952	1.04928951	1.04626155	1.04358257
0	0.24486555	0.20325694	0.37816628	0.56614576	0.75676638
1	0.22668503	0.22013640	0.23265774	0.24696778	0.26172725
2	0.21330981	0.22596537	0.16866452	0.10683170	0.04422289
3	0.22421892	0.21165523	0.26154901	0.31535915	0.37006691
4	0.21773231	0.21686330	0.19831623	0.17954072	0.16079013
5	0.20572924	0.21269842	0.19145031	0.16755647	0.14323741
6	0.21098065	0.19979841	0.23589074	0.27581340	0.31664548
7	0.20238256	0.20412129	0.17563148	0.14547296	0.11498999
8	0.18770412	0.19263515	0.19227677	0.19066024	0.18889651
9	0.19144065	0.18013254	0.20237704	0.22834293	0.25520675
10	0.17990440	0.18452205	0.15444573	0.12119448	0.08723333
11	0.16014016	0.16383814	0.17876009	0.19432064	0.21011089
12	0.16632030	0.15362632	0.15985711	0.16891646	0.17875371
13	0.14941012	0.15886732	0.13502243	0.10681015	0.07741743
14	0.11605440	0.11846545	0.14376904	0.17206675	0.20111542
15	0.13544933	0.11825170	0.10503107	0.09281246	0.08128776
16	0.08952182	0.11545886	0.11202394	0.10227238	0.08956900
17	-0.07069809	-0.06298819	-0.02413897	0.02027964	0.06591204
18	0.03250783	-0.03464954	-0.10283615	-0.16525563	-0.22142868
19	0.55741953	0.55937057	0.53908285	0.51529508	0.49093849
20	0.88894370	0.98023796	1.07460319	1.17192569	1.27212685

NBAR=	18	19	20
SIGMA=	1.04119629	1.03905682	1.03712815
0	0.94188288	1.11701487	1.27985296
1	0.27618665	0.28993935	0.30277012
2	-0.01651625	-0.07394994	-0.12734355
3	0.42327314	0.47365397	0.52052333
4	0.14272703	0.12572434	0.10996716
5	0.11958918	0.09718643	0.07632455
6	0.35647842	0.39427469	0.42949153
7	0.08544301	0.05751850	0.03156598
8	0.18712020	0.18538737	0.18373062
9	0.28158351	0.30672704	0.33023635
10	0.05412359	0.02270402	-0.00658580
11	0.22543523	0.23991875	0.25336979
12	0.18870001	0.19837620	0.20756151
13	0.04839800	0.02061259	-0.00546396
14	0.22951855	0.25651802	0.28171043
15	0.07067804	0.06104927	0.05239538
16	0.07545026	0.06088994	0.04650524
17	0.11056553	0.15303328	0.19267627
18	-0.27139317	-0.31552226	-0.35432806
19	0.46774300	0.44629931	0.42659558
20	1.37509735	1.48078753	1.58910999

DB=25

A= 1.13655318

NBAR= 3

4

5

6

7

SIGMA=

	1.17918782	1.15249014	1.12958732	1.11176890	1.09792085
0	0.36062255	0.33054933	0.33889988	0.30772878	0.32289020
1	0.35907359	0.33044550	0.33614929	0.30929841	0.31854109
2	0.35447861	0.32988389	0.32867501	0.31239770	0.30844343
3	0.34699076	0.32818029	0.31846690	0.31328455	0.29876383
4	0.33685705	0.32439913	0.30784759	0.30862220	0.29330997
5	0.32440655	0.31760963	0.29843720	0.29777042	0.29021789
6	0.31003506	0.30715461	0.29041848	0.28326686	0.28400631
7	0.29418739	0.29286798	0.28243881	0.26910972	0.27111953
8	0.27733824	0.27518846	0.27222255	0.25792604	0.25370035
9	0.25997302	0.25514092	0.25766513	0.24892744	0.23776333
10	0.24256969	0.23418727	0.23796572	0.23815827	0.22709839
11	0.22558256	0.21397850	0.21431783	0.22112799	0.21856211
12	0.20942872	0.19606255	0.18983667	0.19634432	0.20381426
13	0.19447756	0.18161189	0.16869666	0.16752101	0.17712489
14	0.18104346	0.17123052	0.15476863	0.14284038	0.14307378
15	0.16938154	0.16488146	0.15025512	0.13131060	0.11695844
16	0.15968606	0.16194799	0.15484168	0.13801651	0.11591563
17	0.15209093	0.16141220	0.16569975	0.16086882	0.14631812
18	0.14667172	0.16210812	0.17836398	0.19078971	0.19681018
19	0.14344857	0.16299100	0.18818136	0.21546782	0.24298108
20	0.14238952	0.16336252	0.19181916	0.22487692	0.26137662

NBAR= 8

9

10

11

12

SIGMA=

	1.08697589	1.07815662	1.07092035	1.06488679	1.05978467
0	0.29421158	0.31263462	0.28555293	0.30569031	0.27958936
1	0.29771554	0.30636403	0.29118745	0.29731441	0.28743090
2	0.30345276	0.29478396	0.29784190	0.28608160	0.29293240
3	0.30271264	0.28916072	0.29242638	0.28593519	0.28293133
4	0.29297232	0.28897794	0.28063446	0.28497978	0.27569472
5	0.28042435	0.28401505	0.27482384	0.27309046	0.27474203
6	0.27197545	0.27058405	0.27153311	0.26228260	0.26392928
7	0.26661384	0.25689157	0.25971935	0.25612400	0.25026703
8	0.25698671	0.24934473	0.24311463	0.24725002	0.24503889
9	0.23951162	0.24154638	0.23336757	0.22897888	0.23349866
10	0.22020368	0.22450280	0.22619127	0.21863200	0.21400253
11	0.20768775	0.20302285	0.20817161	0.21127681	0.20537445
12	0.20068959	0.19040466	0.18529214	0.18980304	0.19561998
13	0.18613524	0.18516650	0.17585968	0.16800014	0.16880554
14	0.15377717	0.16597781	0.17066998	0.16540304	0.15538881
15	0.11357275	0.12171469	0.13623559	0.14934271	0.15480012
16	0.09504416	0.08143882	0.07862362	0.08656425	0.10187567
17	0.12383340	0.09666130	0.06971088	0.04669108	0.03129880
18	0.19497312	0.18471793	0.16629011	0.14066300	0.10942581
19	0.26942021	0.29373988	0.31504843	0.33257304	0.34565218
20	0.30073397	0.34260315	0.38675478	0.43302231	0.48128030

NBAR= 13 14 15 16 17

SIGMA= 1.05541678 1.05163774 1.04833677 1.04542960 1.04284987

0	0.30078659	0.27667652	0.37217536	0.47444263	0.57816654
1	0.29022208	0.28550136	0.29145131	0.29845570	0.30579246
2	0.28125031	0.28718754	0.25464539	0.21988957	0.18482919
3	0.28466940	0.27669630	0.30330627	0.33202011	0.36128948
4	0.27751568	0.27602975	0.26493600	0.25387106	0.24291139
5	0.26634906	0.26928880	0.25674864	0.24290928	0.22892979
6	0.26384895	0.25681967	0.27597963	0.29721692	0.31900376
7	0.25295302	0.25310584	0.23670463	0.21955042	0.20229912
8	0.23794506	0.24000147	0.23918281	0.23774154	0.23628252
9	0.23251117	0.22566950	0.23742661	0.25121229	0.26552083
10	0.21824060	0.22023561	0.20317957	0.18452559	0.16554695
11	0.19895119	0.20062387	0.20847772	0.21667583	0.22502786
12	0.19373525	0.18640777	0.18959656	0.19433500	0.19950940
13	0.17590225	0.18079127	0.16736575	0.15166129	0.13536223
14	0.14879608	0.15006413	0.16388379	0.17927291	0.19506338
15	0.15097591	0.14137190	0.13406703	0.12733506	0.12097953
16	0.11913672	0.13287850	0.13056065	0.12494721	0.11781950
17	0.02560740	0.02974123	0.05084819	0.07488308	0.09956413
18	0.07462902	0.03872172	0.00196281	-0.03186633	-0.06247911
19	0.35373041	0.35647584	0.34688476	0.33530308	0.32329484
20	0.53142915	0.58337655	0.63705744	0.69240365	0.74936863

NBAR= 18 19 20

SIGMA= 1.04054609 1.03847598 1.03660613

0	0.67705730	0.77473493	0.86395148
1	0.31305200	0.32000713	0.32653283
2	0.15083935	0.11866679	0.08869584
3	0.38984097	0.41696330	0.44227957
4	0.23238968	0.22249192	0.21330856
5	0.21537530	0.20253911	0.19057117
6	0.34032511	0.36062308	0.37959968
7	0.18560184	0.16981277	0.15511223
8	0.23486885	0.23352250	0.23225475
9	0.27961514	0.29309454	0.30573976
10	0.14705815	0.12949654	0.11309256
11	0.23316359	0.24088080	0.24807338
12	0.20476341	0.20989385	0.21478088
13	0.11929194	0.10387135	0.08938096
14	0.21052136	0.22524623	0.23902193
15	0.11511325	0.10977003	0.10494736
16	0.10997267	0.10191087	0.09395452
17	0.12374736	0.14679768	0.16837447
18	-0.08986219	-0.11418571	-0.13569952
19	0.31179230	0.30111707	0.29126782
20	0.80788852	0.86793400	0.92945547



DB=30

A= 1.31995942

N5AR= 3 4 5 6 7

SIGMA=

	1.14546929	1.13378383	1.11795694	1.10391277	1.09228431
0	0.41137788	0.39965000	0.39892609	0.37944478	0.38364070
1	0.40973410	0.39845101	0.39661392	0.37927647	0.38048024
2	0.40482349	0.39478789	0.39005468	0.37799183	0.37253840
3	0.39670999	0.38848353	0.38022566	0.37378592	0.36305637
4	0.38550605	0.37930903	0.36830548	0.36507877	0.35410782
5	0.37138025	0.36706742	0.35520119	0.35165077	0.34487737
6	0.35456600	0.35168315	0.34120378	0.33489434	0.33268826
7	0.33536945	0.33327714	0.32592507	0.31698218	0.31583919
8	0.31417494	0.31221041	0.30855326	0.29947104	0.29556989
9	0.29144608	0.28908614	0.28933176	0.28226676	0.27517523
10	0.26772128	0.26470888	0.26506957	0.26369562	0.25690170
11	0.24360278	0.24062882	0.23947109	0.24174976	0.23948392
12	0.21973916	0.21594602	0.21313852	0.21580911	0.21892302
13	0.19680185	0.19341315	0.18822589	0.18776827	0.19238941
14	0.17545686	0.17315491	0.16686030	0.16176864	0.16218104
15	0.15633372	0.15571732	0.15053921	0.14252079	0.13609748
16	0.13999385	0.14143348	0.13972593	0.13304606	0.12314202
17	0.12690077	0.13044358	0.13379243	0.13306772	0.12734644
18	0.11173947	0.12273975	0.13132856	0.13898565	0.14366619
19	0.11167370	0.11822186	0.13069983	0.14552705	0.16108098
20	0.10978286	0.11674892	0.13064547	0.14825097	0.16833961

NBAR= 8 9 10 11 12

SIGMA=

	1.08274533	1.07486916	1.06829467	1.06274264	1.05800144
0	0.36553349	0.37283999	0.35609438	0.36520908	0.34939357
1	0.36651836	0.36863840	0.35832184	0.35985132	0.35289439
2	0.36697213	0.35991682	0.35948692	0.35134450	0.35356739
3	0.36234263	0.35275977	0.35255635	0.34732743	0.34424971
4	0.35135710	0.34699528	0.34065797	0.34142440	0.33498425
5	0.33737697	0.33726693	0.33058330	0.32820341	0.32782729
6	0.32420854	0.32169442	0.32063496	0.31429778	0.31407571
7	0.31153444	0.30479483	0.30498710	0.30292996	0.29765388
8	0.29567531	0.29021815	0.28575982	0.28702091	0.28492884
9	0.27487497	0.27480321	0.26944342	0.26629922	0.26806276
10	0.25243121	0.25390453	0.25402167	0.24927776	0.24624669
11	0.23313675	0.23017107	0.23243892	0.23360473	0.22995992
12	0.21671944	0.21091892	0.20795448	0.21014699	0.21301000
13	0.19667243	0.19582049	0.19066769	0.18637249	0.18676047
14	0.16770204	0.17392924	0.17621367	0.17325901	0.16783329
15	0.13481740	0.13927129	0.14695928	0.15385515	0.15666687
16	0.11331119	0.10682939	0.10572966	0.11015470	0.11841482
17	0.11695793	0.10391002	0.09038603	0.07873846	0.07092128
18	0.14426528	0.14029927	0.13179245	0.11920744	0.10337208
19	0.17638059	0.19071295	0.20350654	0.21428381	0.22264396
20	0.19033452	0.21391884	0.23889700	0.26513674	0.29254352

NBAR=	13	14	15	16	17
SIGMA=	1.05391085	1.05034940	1.04722210	1.04445596	1.04199211
0	0.35965169	0.34520378	0.39652154	0.45132882	0.50698314
1	0.35308293	0.34930265	0.35152320	0.35441116	0.35757444
2	0.34584918	0.34796894	0.32910403	0.30924638	0.28933460
3	0.34393159	0.33844999	0.35206671	0.36684591	0.38200624
4	0.33480656	0.33293826	0.32593496	0.31908237	0.31237719
5	0.32213572	0.32280025	0.31506757	0.30675618	0.29845584
6	0.31302260	0.30829682	0.31803861	0.32892893	0.34017827
7	0.29826556	0.29756420	0.28788688	0.27792481	0.26798064
8	0.28030960	0.28079828	0.27975829	0.27844048	0.27716927
9	0.26687578	0.26258055	0.26855742	0.27564604	0.28305185
10	0.24809470	0.24873335	0.23898597	0.22846477	0.21781312
11	0.22612500	0.22675899	0.23077914	0.23498647	0.23929878
12	0.21169829	0.20747551	0.20906438	0.21149437	0.21416673
13	0.19051974	0.19303931	0.18554073	0.17686592	0.16789373
14	0.16430657	0.16504980	0.17261675	0.18098417	0.18955667
15	0.15452336	0.14930905	0.14540125	0.14180487	0.13839889
16	0.12767253	0.13501646	0.13361898	0.13051220	0.12662960
17	0.06813496	0.07052274	0.08207055	0.09511568	0.10848460
18	0.08538784	0.06659151	0.04713308	0.02910797	0.01268861
19	0.22825405	0.23090928	0.22675645	0.22147286	0.21588196
20	0.32104629	0.35058223	0.38110860	0.41258152	0.44497141

NBAR=	18	19	20
SIGMA=	1.03978474	1.03779568	1.03599463
0	0.56125249	0.61288167	0.66119644
1	0.36078560	0.36391327	0.36688109
2	0.27006539	0.25181629	0.23478212
3	0.39687531	0.41107015	0.42438095
4	0.30597732	0.29996872	0.29439096
5	0.29044804	0.28287572	0.27581053
6	0.35124991	0.36184359	0.37179381
7	0.25838163	0.24930459	0.24083913
8	0.27597035	0.27484841	0.27380389
9	0.29038594	0.29743370	0.30407495
10	0.20744812	0.19759350	0.18836812
11	0.24352127	0.24754561	0.25131299
12	0.21689450	0.21957026	0.22212966
13	0.15904432	0.15055119	0.14254570
14	0.19795573	0.20597349	0.21349591
15	0.13524182	0.13235237	0.12973101
16	0.12237760	0.11801458	0.11370581
17	0.12159283	0.13411302	0.14586632
18	-0.00209515	-0.01531303	-0.02708000
19	0.21048072	0.20544252	0.20076969
20	0.47823989	0.51236901	0.54732874

RR=35

A= 1.50324775

NBAR= 4 5 6 7 8

SIGMA= 1.11336325 1.10503227 1.09507197 1.08591640 1.07794678

0	0.46022724	0.45750600	0.44560608	0.44456014	0.43255796
1	0.45818926	0.45511902	0.44420476	0.44173922	0.43187062
2	0.45211000	0.44814047	0.43967242	0.43406780	0.42855436
3	0.44209297	0.43705822	0.43126655	0.42324204	0.42035251
4	0.42830905	0.42251171	0.41839937	0.41044626	0.40673279
5	0.41099510	0.40510464	0.40115802	0.39548979	0.38959322
6	0.39045376	0.38525960	0.38042542	0.37728968	0.37112930
7	0.36705517	0.36317289	0.35750477	0.35525459	0.35147513
8	0.34124081	0.33888790	0.33347386	0.33026493	0.32904288
9	0.31352822	0.31245812	0.30868429	0.30426544	0.30319769
10	0.28451488	0.28413479	0.28275002	0.27874862	0.27589582
11	0.25487803	0.25450309	0.25507433	0.25350278	0.24993354
12	0.22536772	0.22451006	0.22562197	0.22691084	0.22559479
13	0.19679008	0.19536788	0.19546540	0.19779786	0.19993196
14	0.16997996	0.16836323	0.16673706	0.16739059	0.17041380
15	0.14576295	0.14463708	0.14195221	0.13963053	0.13956009
16	0.12490939	0.12500902	0.12303528	0.11925266	0.11517525
17	0.10808480	0.10990033	0.11057137	0.10883466	0.10469004
18	0.09580203	0.09937126	0.10369384	0.10698500	0.10832867
19	0.08838132	0.09324462	0.10067347	0.10913400	0.11780716
20	0.08592358	0.09125783	0.09988811	0.11050049	0.12250428

NBAR= 9 10 11 12 13

SIGMA= 1.07113025 1.06530267 1.06029591 1.05596440 1.05218919

0	0.43394393	0.42295228	0.42400171	0.41585528	0.42001931
1	0.43058058	0.42301371	0.42202122	0.41667082	0.41538259
2	0.42255262	0.42029120	0.41416752	0.41382617	0.40827881
3	0.41313656	0.41111432	0.40662740	0.40350964	0.40204348
4	0.40238947	0.39725833	0.39611025	0.39126018	0.38990172
5	0.38768221	0.38251579	0.37984663	0.37839920	0.37422349
6	0.36822061	0.36622236	0.36158892	0.36039109	0.35884785
7	0.34660661	0.34551468	0.34333650	0.33956707	0.33908660
8	0.32506310	0.32174850	0.32156327	0.31965454	0.31648113
9	0.30227392	0.29867328	0.29635204	0.29671466	0.29552737
10	0.27608557	0.27557951	0.27256068	0.27053096	0.27116370
11	0.24811021	0.24900278	0.24930117	0.24705913	0.24476452
12	0.22247958	0.22085536	0.22193128	0.22333235	0.22248505
13	0.19946472	0.19679240	0.19458848	0.19486224	0.19690616
14	0.17373327	0.17499662	0.17352125	0.17075415	0.16900933
15	0.14222007	0.14645194	0.15022062	0.15181760	0.15077021
16	0.11251767	0.11243359	0.11509972	0.11970284	0.12478504
17	0.09889710	0.09240167	0.08707980	0.08340712	0.08227659
18	0.10728972	0.10377794	0.09798052	0.09030862	0.08134068
19	0.12615976	0.13379760	0.14040813	0.14573749	0.14957846
20	0.13559131	0.14958176	0.16436042	0.17984944	0.19599261

NBAR=	14	15	16	17	18
SIGMA=	1.04887550	1.04594642	1.04334106	1.04100955	1.03891236
0	0.41088811	0.43771838	0.46638599	0.49555224	0.52412707
1	0.41208376	0.41219267	0.41276393	0.41358125	0.41451420
2	0.40824297	0.39690140	0.38519376	0.37355977	0.36234067
3	0.39791758	0.40431528	0.41139318	0.41876254	0.42606813
4	0.38789601	0.38313638	0.37657600	0.37418134	0.37002011
5	0.37362969	0.36855528	0.36327756	0.35808607	0.35311406
6	0.35542305	0.35996844	0.36517281	0.37063302	0.37606576
7	0.33796386	0.33203933	0.32605725	0.32014550	0.31446273
8	0.31615776	0.31504798	0.31384080	0.31270700	0.31165394
9	0.29272141	0.29556181	0.29901784	0.30267524	0.30633040
10	0.27115552	0.26553433	0.25955699	0.25354030	0.24769385
11	0.24491475	0.24690522	0.24899691	0.25115913	0.25329089
12	0.22009005	0.22087918	0.22211649	0.22348459	0.22488756
13	0.19824744	0.19414036	0.18942807	0.18456320	0.17976037
14	0.16954553	0.17374818	0.17834080	0.18302834	0.18762000
15	0.14809441	0.14613995	0.14433923	0.14262096	0.14101596
16	0.12881715	0.12811236	0.12652002	0.12452435	0.12233093
17	0.08381463	0.09023474	0.09739135	0.10469392	0.11185102
18	0.07179661	0.06176209	0.05239095	0.04378707	0.03598142
19	0.15179958	0.15029091	0.14814268	0.14578119	0.14346785
20	0.21274381	0.23007159	0.24794608	0.26634705	0.28524971

NBAR=	19	20
SIGMA=	1.03701600	1.03529365
0	0.55143119	0.57709980
1	0.41548286	0.41643738
2	0.35171925	0.34178862
3	0.43310135	0.43974287
4	0.36612629	0.36251249
5	0.34842592	0.34405173
6	0.38130814	0.38626666
7	0.30909310	0.30407825
8	0.31067811	0.30977545
9	0.30986881	0.31322400
10	0.24212983	0.23690816
11	0.25533478	0.25725852
12	0.22626984	0.22759762
13	0.17513969	0.17076980
14	0.19201064	0.19614174
15	0.13953900	0.13818953
16	0.12007143	0.11783097
17	0.11869814	0.12514404
18	0.02895134	0.02264803
19	0.14129486	0.13926469
20	0.30464176	0.32450538

DR=40

A= 1.68649887

NRAR=	4	5	6	7	8
SIGMA=	1.09161256	1.09095825	1.09537792	1.07885547	1.07260233
0	0.51397361	0.51362998	0.50745000	0.50462034	0.49645994
1	0.51123319	0.51087435	0.50506950	0.50164136	0.49453651
2	0.50310551	0.50270839	0.49784732	0.49311502	0.48819461
3	0.48986059	0.48942122	0.48563382	0.47996256	0.47645277
4	0.47191529	0.47145290	0.46842771	0.46296212	0.45925027
5	0.44979166	0.44934348	0.44657496	0.44233805	0.43779582
6	0.42407289	0.42368163	0.42081335	0.41795849	0.41352377
7	0.39536671	0.39506568	0.39212026	0.38995094	0.38691736
8	0.36428382	0.36408547	0.36144372	0.35914967	0.35763255
9	0.33143501	0.33132742	0.32947392	0.32691920	0.32577875
10	0.29744519	0.29739776	0.29659386	0.29445703	0.29273539
11	0.26297788	0.26295405	0.26304406	0.26218198	0.26033033
12	0.22876039	0.22873222	0.22920802	0.22980242	0.22918936
13	0.19559884	0.19555783	0.19584902	0.19710581	0.19829335
14	0.16437385	0.16433373	0.16415166	0.16486714	0.16665458
15	0.13601179	0.13600230	0.13552956	0.13509362	0.13558846
16	0.11143183	0.11148598	0.11129162	0.11029445	0.10901503
17	0.09147511	0.09161489	0.09233614	0.09223294	0.09096369
18	0.07682626	0.07705238	0.07902144	0.08106297	0.08236193
19	0.06794096	0.06823043	0.07125775	0.07549877	0.08021297
20	0.06499201	0.06530450	0.06674080	0.07389706	0.08016238

NRAR=	9	10	11	12	13
SIGMA=	1.06695332	1.06195298	1.05755231	1.05367747	1.05025449
0	0.49496472	0.48729462	0.48712524	0.48014350	0.48096778
1	0.49172176	0.48584330	0.48357136	0.47915768	0.47707379
2	0.48308366	0.48001831	0.47510707	0.47341541	0.46908995
3	0.47084627	0.46802541	0.46406604	0.46098979	0.45892890
4	0.45525120	0.45097436	0.44890711	0.44502314	0.44317020
5	0.43523388	0.43110753	0.42841162	0.42647195	0.42319108
6	0.41070501	0.40841750	0.40486375	0.40323019	0.40149669
7	0.38335625	0.38177537	0.37969615	0.37686704	0.37586969
8	0.35475121	0.35225981	0.35144384	0.34976881	0.34748683
9	0.32467949	0.32224650	0.32052511	0.32024843	0.31917509
10	0.29246409	0.29182943	0.28991479	0.28855380	0.28862453
11	0.25929665	0.25961015	0.25959835	0.25825883	0.25691124
12	0.22767876	0.22690128	0.22748879	0.22821687	0.22774030
13	0.19820936	0.19700445	0.19602659	0.19631896	0.19751273
14	0.16856854	0.16943235	0.16887750	0.16763961	0.16692671
15	0.13733215	0.13981063	0.14201574	0.14306689	0.14271937
16	0.10828005	0.10871715	0.11047401	0.11317490	0.11608559
17	0.08876234	0.08617254	0.08384426	0.08236383	0.08212665
18	0.08251460	0.08137406	0.07898125	0.07552164	0.07128697
19	0.08496431	0.08945735	0.09347266	0.09483970	0.09942307
20	0.08722957	0.09492620	0.10314653	0.11162174	0.12090431

NBAR=	14	15	16	17	18
SIGMA=	1.04721802	1.04451090	1.04208593	1.03990299	1.03792956
0	0.47477051	0.48810672	0.50242245	0.51711853	0.53160740
1	0.47404151	0.47297329	0.47225343	0.47175985	0.47141477
2	0.46766747	0.46065803	0.45338977	0.44625440	0.43941096
3	0.45556470	0.45798895	0.46084542	0.46394268	0.46709255
4	0.44099386	0.43748052	0.43417458	0.43103651	0.42808977
5	0.42194027	0.41835506	0.41475213	0.41126682	0.40795740
6	0.39884261	0.40056560	0.40268736	0.40500452	0.40736742
7	0.37458679	0.37076089	0.36701679	0.36334061	0.35982568
8	0.34679068	0.34570875	0.34461714	0.34360400	0.34266869
9	0.31727742	0.31846229	0.31999235	0.32165501	0.32334479
10	0.28836031	0.28509336	0.28167267	0.27824987	0.27492838
11	0.25689121	0.25763826	0.25884744	0.25970124	0.26094858
12	0.22644210	0.22686504	0.22751821	0.22823667	0.22897291
13	0.19830174	0.19614584	0.19367452	0.19111797	0.18858498
14	0.16740298	0.16981734	0.17240639	0.17502923	0.17759268
15	0.14149942	0.14066034	0.13988316	0.13912796	0.13841323
16	0.11841383	0.11818792	0.11749617	0.11658698	0.11556346
17	0.08323044	0.08689640	0.09090481	0.09496592	0.09893856
18	0.06665693	0.06167624	0.05698076	0.05262657	0.04864145
19	0.10113413	0.10082333	0.10015436	0.09934300	0.09852423
20	0.13035724	0.14015575	0.15027758	0.16070776	0.17142924

NBAR=	19	20
SIGMA=	1.03613737	1.03450353
0	0.54554288	0.55872426
1	0.47116653	0.47098030
2	0.43294177	0.42688742
3	0.47017850	0.47313008
4	0.42534246	0.42279414
5	0.40484851	0.40194957
6	0.40968649	0.41190728
7	0.35650914	0.35340849
8	0.34180523	0.34100792
9	0.32500072	0.32658576
10	0.27176330	0.26878460
11	0.26195974	0.26291727
12	0.22969932	0.23039683
13	0.18613727	0.18381129
14	0.18004552	0.18235872
15	0.13774737	0.13713400
16	0.11449264	0.11341875
17	0.10274273	0.10633313
18	0.04502254	0.04175248
19	0.09774604	0.09701036
20	0.16243346	0.19370625

DB=45

A= 1.86973822

NBAR= 5 6 7 8 9

SIGMA=

	1.07588492	1.07484736	1.07114387	1.06673692	1.06235391
0	0.56674220	0.56562542	0.56318391	0.55782813	0.55528440
1	0.56345216	0.56238545	0.55975012	0.55487936	0.55173395
2	0.55366403	0.55272572	0.54968235	0.54583845	0.54167385
3	0.53762921	0.53684479	0.53355707	0.53044967	0.52616218
4	0.51578016	0.51512124	0.51202711	0.50899083	0.50562037
5	0.48873558	0.48814849	0.48563985	0.48242513	0.47993018
6	0.45728595	0.45673201	0.45488656	0.45191723	0.44951796
7	0.42235196	0.42183489	0.42041839	0.41827181	0.41574033
8	0.38491987	0.38448390	0.38320761	0.38194668	0.37995131
9	0.34596891	0.34566951	0.34447046	0.34359960	0.34266398
10	0.30641205	0.30627773	0.30537476	0.30445467	0.30412720
11	0.26706912	0.26707841	0.26675490	0.26594041	0.26544391
12	0.22868067	0.22876914	0.22907494	0.22892075	0.22833656
13	0.19195508	0.19204893	0.19269093	0.19342037	0.19359727
14	0.15762778	0.15768440	0.15821884	0.15930621	0.16049911
15	0.12650367	0.12653480	0.12671593	0.12732907	0.12852596
16	0.09945726	0.09952076	0.09951741	0.09940943	0.09951319
17	0.07737853	0.07754284	0.07783122	0.07771617	0.07714888
18	0.06107123	0.06137289	0.06237326	0.06330989	0.06379998
19	0.05112817	0.05154659	0.05328179	0.05562927	0.05820613
20	0.04781840	0.04828201	0.05032377	0.05331382	0.05694421

NBAR= 10 11 12 13 14

SIGMA=

	1.05825564	1.05451864	1.05114536	1.04811019	1.04537946
0	0.54970810	0.54798786	0.54285146	0.54192271	0.53737841
1	0.54707132	0.54429836	0.54051848	0.53807337	0.53523192
2	0.53848076	0.53442019	0.53211811	0.52854000	0.52671515
3	0.52320719	0.51973185	0.51680471	0.51450460	0.51161187
4	0.50209012	0.49972151	0.49649355	0.49442014	0.49225828
5	0.47664595	0.47412581	0.47205783	0.46936405	0.46782212
6	0.44734539	0.44456634	0.44283230	0.44110198	0.43894861
7	0.41413969	0.41230284	0.41012312	0.40894930	0.40766691
8	0.37811712	0.37713117	0.37572428	0.37403676	0.37322291
9	0.34105522	0.33980735	0.33931077	0.33841127	0.33710044
10	0.30359605	0.30241739	0.30152927	0.30139099	0.30107763
11	0.26556896	0.26551177	0.26476719	0.26401999	0.26396549
12	0.22808086	0.22848252	0.22893222	0.22873983	0.22810952
13	0.19322499	0.19294695	0.19329310	0.19407945	0.19462824
14	0.16119502	0.16117536	0.16079236	0.16066197	0.16113392
15	0.13007404	0.13147520	0.13227550	0.13233918	0.13193349
16	0.10013582	0.10137360	0.10305741	0.10482315	0.10624482
17	0.07633279	0.07557763	0.07518848	0.07538484	0.07623482
18	0.06367046	0.06288650	0.06151280	0.05968540	0.05759719
19	0.06077286	0.06316346	0.06525540	0.06695487	0.06819853
20	0.06104707	0.06552266	0.07030789	0.07536056	0.08064749

	15	16	17	18	19
NBAR=	15	16	17	18	19
SIGMA=	1.04291749	1.04069202	1.03867352	1.03683721	1.03516048
0	0.54335315	0.54988980	0.55671884	0.56354234	0.57017747
1	0.53354137	0.53212635	0.53091745	0.52986702	0.52894028
2	0.52179053	0.51694464	0.51225075	0.50777818	0.50355986
3	0.51189542	0.51247708	0.51326437	0.51415634	0.51508689
4	0.48946825	0.48687012	0.48442990	0.48215155	0.48003212
5	0.46510348	0.46244777	0.45991491	0.45752749	0.45529175
6	0.43918716	0.43968069	0.44032853	0.44105184	0.44180065
7	0.40508873	0.40258480	0.40016692	0.39786715	0.39570026
8	0.37223137	0.37126599	0.37037191	0.36954618	0.36878303
9	0.33745429	0.33800320	0.33864061	0.33931291	0.33998790
10	0.29917624	0.29721248	0.29525710	0.29336047	0.29154950
11	0.26442896	0.26491537	0.26542664	0.26593796	0.26643459
12	0.22839012	0.22878107	0.22919868	0.22962075	0.23003448
13	0.19359631	0.19239383	0.19113638	0.18987889	0.18865347
14	0.16260184	0.16413852	0.16567673	0.16717273	0.16860280
15	0.13171628	0.13151125	0.13129710	0.13108521	0.13089193
16	0.10633891	0.10616366	0.10586458	0.10549282	0.10508258
17	0.07840491	0.08072177	0.08304686	0.08531390	0.08748526
18	0.05527131	0.05304681	0.05096011	0.04903016	0.04726101
19	0.06836411	0.06833269	0.06821030	0.06806477	0.06792020
20	0.08615370	0.09185563	0.09774330	0.10380437	0.11003214

NBAR= 20

SIGMA=

1.03362481

0	0.57651182
1	0.52811184
2	0.49961015
3	0.51601271
4	0.47806572
5	0.45320762
6	0.44254243
7	0.39367225
8	0.36807712
9	0.34064498
10	0.28983918
11	0.26690753
12	0.23043187
13	0.18747998
14	0.16995336
15	0.13069109
16	0.10465715
17	0.08953924
18	0.04564873
19	0.06777747
20	0.11641807



DR=50

A= 2.05297384

NEAR= 6 7 8 9 10

SIGMA=

	1.06358004	1.06282659	1.06037748	1.05734897	1.05422182
0	0.62049161	0.61986933	0.61695402	0.61451882	0.61048058
1	0.61644284	0.61580020	0.61306928	0.61039788	0.60680676
2	0.60444406	0.60376234	0.60143553	0.59838840	0.59554626
3	0.58492064	0.58422900	0.58223502	0.57922680	0.57660101
4	0.55853349	0.55789539	0.55602732	0.55353721	0.55077451
5	0.52613139	0.52560318	0.52379073	0.52182657	0.51933347
6	0.48871496	0.48831100	0.48671095	0.48495704	0.48315642
7	0.44741316	0.44710542	0.44592401	0.44428588	0.44293938
8	0.40345672	0.40320732	0.40246894	0.40122573	0.39995443
9	0.35812801	0.35792542	0.35745375	0.35682249	0.35582270
10	0.31268054	0.31254782	0.31217533	0.31195516	0.31160791
11	0.26824503	0.26821328	0.26796966	0.26780793	0.26790546
12	0.22575917	0.22583007	0.22588299	0.22577762	0.22581174
13	0.18595731	0.18608883	0.18649827	0.18677405	0.18682221
14	0.14943292	0.14956301	0.15013637	0.15088288	0.15145753
15	0.11674820	0.11683876	0.11727571	0.11805820	0.11905214
16	0.08853500	0.08860023	0.08879388	0.08913350	0.08972648
17	0.06552686	0.06562142	0.06579110	0.06583318	0.06576412
18	0.04848931	0.04866407	0.04915584	0.04959603	0.04980125
19	0.03806376	0.03832340	0.03926267	0.04052879	0.04191515
20	0.03458503	0.03488039	0.03602535	0.03771226	0.03977744

NEAR= 11 12 13 14 15

SIGMA=

	1.05120249	1.04837343	1.04576011	1.04336266	1.04116836
0	0.60822092	0.60427428	0.60252865	0.59897440	0.60101244
1	0.60405281	0.60081046	0.59830212	0.59565557	0.59368727
2	0.59222222	0.58978541	0.58674606	0.58468184	0.58106349
3	0.57366016	0.57100281	0.56870830	0.56616657	0.56535468
4	0.54850759	0.54581962	0.54375970	0.54170441	0.53937815
5	0.51715068	0.51519444	0.51295088	0.51134914	0.50917690
6	0.48101646	0.47939569	0.47779802	0.47601662	0.47552768
7	0.44143675	0.43976108	0.43861319	0.43743134	0.43560002
8	0.39905086	0.39793032	0.39667663	0.39589099	0.39502814
9	0.35496485	0.35446857	0.35376663	0.35286023	0.35283623
10	0.31093117	0.31038832	0.31022012	0.30995766	0.30886560
11	0.26790315	0.26755052	0.26718978	0.26717946	0.26743159
12	0.22614824	0.22649568	0.22650580	0.22628102	0.22652460
13	0.18691015	0.18729295	0.18788147	0.18833054	0.18793951
14	0.15170324	0.15176380	0.15193838	0.15240327	0.15337200
15	0.11999746	0.12065004	0.12092511	0.12094894	0.12105848
16	0.09061450	0.09171674	0.09285158	0.09381050	0.09404666
17	0.06570359	0.06579602	0.06615596	0.06682560	0.06816203
18	0.04969879	0.04928995	0.04862708	0.04780131	0.04682133
19	0.04328731	0.04455115	0.04563751	0.04649909	0.04679948
20	0.04212590	0.04469896	0.04745827	0.05037652	0.05343544

	NBAR= 16	17	18	19	20
SIGMA=	1.03916097	1.03732242	1.03563626	1.03408615	1.03265815
0	0.60339662	0.60601406	0.60871591	0.61140496	0.61401757
1	0.59193609	0.59036501	0.58894599	0.58765589	0.58647654
2	0.57756407	0.57421029	0.57103108	0.56803733	0.56523182
3	0.56475742	0.56433301	0.56402846	0.56380575	0.56363799
4	0.553721300	0.553518584	0.553329484	0.553153411	0.552989680
5	0.50708975	0.50511415	0.50325813	0.50152106	0.49989973
6	0.47520671	0.47500664	0.47488697	0.47481989	0.47478599
7	0.43384123	0.43215569	0.43055736	0.42905150	0.42763941
8	0.39419888	0.39342716	0.39271078	0.39204548	0.39142731
9	0.35292131	0.35306429	0.35323895	0.35342874	0.35362254
10	0.30774786	0.30663698	0.30555770	0.30452342	0.30354192
11	0.26768930	0.26795741	0.26822462	0.26848415	0.26873178
12	0.22681394	0.22710807	0.22739736	0.22767656	0.22794243
13	0.18745092	0.18692168	0.18637942	0.18584114	0.18531795
14	0.15435567	0.15532628	0.15626396	0.15715832	0.15800352
15	0.12115750	0.12123470	0.12129694	0.12134888	0.12139386
16	0.09414685	0.09417261	0.09414869	0.09409242	0.09401607
17	0.06955459	0.07093832	0.07228264	0.07357026	0.07479104
18	0.04586558	0.04495447	0.04410061	0.04330919	0.04258104
19	0.04699586	0.04713741	0.04725669	0.04736503	0.04746236
20	0.05662047	0.05992161	0.06332935	0.06683808	0.07044165

DR=55

A= 2.23620829

NBAR= 7 8 9 10 11

SIGMA=

	1.05395046	1.05355251	1.05195662	1.04986355	1.04761215
0	0.67445851	0.67397983	0.67242963	0.66974561	0.66759291
1	0.66964206	0.66918526	0.66757004	0.66505379	0.66272765
2	0.65536100	0.65495440	0.65325211	0.65112681	0.64856144
3	0.63212270	0.63176435	0.63013272	0.62817504	0.62586869
4	0.60076882	0.60044188	0.59905516	0.59714458	0.59525812
5	0.56243921	0.56213948	0.56101569	0.55933552	0.55762149
6	0.51849636	0.51824155	0.51726583	0.51602250	0.51447190
7	0.47043050	0.47024239	0.46942483	0.46848634	0.46737312
8	0.41977883	0.41965965	0.41906748	0.41829325	0.41759988
9	0.36807424	0.36800443	0.36770231	0.36715956	0.36662384
10	0.31680526	0.31676465	0.31667785	0.31650840	0.31617009
11	0.26735272	0.26734013	0.26733877	0.26744258	0.26750495
12	0.22089252	0.22092075	0.22098420	0.22113114	0.22142498
13	0.17830184	0.17837351	0.17858849	0.17878099	0.17901392
14	0.14013701	0.14022979	0.14061281	0.14103618	0.14135808
15	0.10672662	0.10680723	0.10720921	0.10780926	0.10844573
16	0.07835135	0.07840559	0.07866132	0.07909774	0.07970694
17	0.05540965	0.05545639	0.05559873	0.05574992	0.05592308
18	0.03845595	0.03852842	0.03877097	0.03899764	0.03911796
19	0.02806618	0.02817804	0.02866023	0.02932666	0.03006244
20	0.02459328	0.02472366	0.02533065	0.02625523	0.02740707

NBAR= 12 13 14 15 16

SIGMA=

	1.04536751	1.04320851	1.04117076	1.03926584	1.03749459
0	0.66455099	0.66256347	0.65968252	0.65970542	0.65994792
1	0.66004246	0.65769381	0.65529202	0.65327495	0.65141679
2	0.64631824	0.64375759	0.64170331	0.63888678	0.63617878
3	0.62360705	0.62150069	0.61928343	0.61798362	0.61683311
4	0.59309444	0.59121696	0.58935165	0.58737472	0.58551697
5	0.55594319	0.55410454	0.55259608	0.55081601	0.54910978
6	0.51310374	0.51172797	0.51026430	0.50947854	0.50880001
7	0.46612968	0.46512715	0.46410765	0.46276625	0.46147889
8	0.41676844	0.41585765	0.41517986	0.41446634	0.41377912
9	0.36623101	0.36572557	0.36511390	0.36495450	0.36485299
10	0.31587756	0.31575753	0.31558358	0.31498194	0.31436657
11	0.26739880	0.26728193	0.26733338	0.26751142	0.26768596
12	0.22172821	0.22186425	0.22187672	0.22212122	0.22237976
13	0.17939114	0.17986651	0.18026542	0.18022670	0.18012981
14	0.14160635	0.14190956	0.14235072	0.14303889	0.14372316
15	0.10897047	0.10931895	0.10953987	0.10979758	0.11003916
16	0.08043805	0.08119418	0.08186430	0.08216327	0.08238865
17	0.05617032	0.05654268	0.05706206	0.05791286	0.05878317
18	0.03910084	0.03895435	0.03871475	0.03838181	0.03804583
19	0.03079099	0.03145822	0.03202694	0.03231582	0.03255376
20	0.02873136	0.03019292	0.03176752	0.03343890	0.03519463

	NBAR= 17	18	19	20
SIGMA=	1.03585111	1.03432791	1.03291526	1.03160428
0	0.66037215	0.66090771	0.66150435	0.66212644
1	0.64970394	0.64812374	0.64666287	0.64530977
2	0.63359226	0.63114161	0.62883111	0.62665989
3	0.61581902	0.61491683	0.61410617	0.61337122
4	0.58376866	0.58212972	0.58059601	0.57916266
5	0.54749272	0.54596962	0.54453920	0.54319878
6	0.50821093	0.50769286	0.50723140	0.50681569
7	0.46024604	0.45907536	0.45796918	0.45692788
8	0.41313273	0.41252707	0.41196002	0.41142946
9	0.36478686	0.36474445	0.36471789	0.36470157
10	0.31375269	0.31315288	0.31257424	0.31202123
11	0.26786152	0.26803328	0.26819848	0.26835538
12	0.22263243	0.22287520	0.22310617	0.22332434
13	0.18000136	0.17785472	0.17969881	0.17953993
14	0.14439092	0.14503282	0.14564429	0.14622282
15	0.11025766	0.11045649	0.11063853	0.11080610
16	0.08256858	0.08271396	0.08283314	0.08293238
17	0.05964210	0.06047507	0.06127389	0.06203360
18	0.03771719	0.03740327	0.03710810	0.03683354
19	0.03276150	0.03295338	0.03313398	0.03330254
20	0.03702616	0.03892582	0.04088890	0.04291062

NR=60

NR= 2.41944236

NBAR=	8	9	10	11	12
SIGMA=	1.04629153	1.04619595	1.04519355	1.04375638	1.04213387
0	0.72897438	0.72886895	0.72755777	0.72595548	0.72373902
1	0.72326519	0.72315815	0.72191572	0.72024598	0.71820199
2	0.70638349	0.70627565	0.70516643	0.70345500	0.70165121
3	0.67903708	0.67893577	0.67791931	0.67637160	0.67463208
4	0.64232808	0.64224112	0.64129422	0.63999306	0.63839004
5	0.59768567	0.59761459	0.59680047	0.59566286	0.59438305
6	0.54680648	0.54674819	0.54612767	0.54515662	0.54413289
7	0.49157545	0.49152887	0.49107624	0.49038018	0.48953148
8	0.43394708	0.43391512	0.43357924	0.43314819	0.43259479
9	0.37581305	0.37579755	0.37559057	0.37531217	0.37505665
10	0.31890736	0.31890475	0.31885942	0.31873339	0.31861144
11	0.26476360	0.26476796	0.26484408	0.26493447	0.26496217
12	0.21468028	0.21468960	0.21480874	0.21503293	0.21528912
13	0.16964537	0.16966168	0.16980978	0.17003633	0.17035736
14	0.13024501	0.13026807	0.13048806	0.13075528	0.13103020
15	0.09665878	0.09668244	0.09695199	0.09733510	0.09772142
16	0.06882099	0.06883853	0.06905359	0.06941631	0.06987866
17	0.04669449	0.04670645	0.04682527	0.04700383	0.04724073
18	0.03047352	0.03048740	0.03060940	0.03074164	0.03083726
19	0.02054680	0.02056800	0.02080036	0.02114198	0.02152767
20	0.01722590	0.01725110	0.01735134	0.01804105	0.01866920

NBAR=	13	14	15	16	17
SIGMA=	1.04045995	1.03880717	1.03721257	1.03569428	1.03426117
0	0.72188493	0.71955400	0.71865205	0.71787617	0.71722760
1	0.71619468	0.71411383	0.71221399	0.71040745	0.70870133
2	0.69959140	0.69772799	0.69547712	0.69329240	0.69119096
3	0.67286058	0.67099269	0.66956958	0.66823258	0.66698904
4	0.63682497	0.63522651	0.63356339	0.63196836	0.63044643
5	0.59295084	0.59164217	0.59018950	0.58877975	0.58742882
6	0.54304140	0.54187871	0.54104280	0.54026462	0.53954408
7	0.48874224	0.48792160	0.48693355	0.48597344	0.48504616
8	0.43196947	0.43143786	0.43088097	0.43033636	0.42981530
9	0.37472941	0.37433947	0.37416708	0.37402119	0.37389386
10	0.31855913	0.31847483	0.31817417	0.31786261	0.31754756
11	0.26490555	0.26508710	0.26524747	0.26540194	0.26555307
12	0.21548066	0.21561540	0.21586273	0.21611237	0.21635357
13	0.17074022	0.17109292	0.17122931	0.17133267	0.17141329
14	0.13134775	0.13173772	0.13225013	0.13275752	0.13325217
15	0.09805098	0.09832878	0.09862627	0.09891241	0.09918118
16	0.07037903	0.07085101	0.07114688	0.07140581	0.07163892
17	0.04754861	0.04793274	0.04848272	0.04904206	0.04959449
18	0.03088145	0.03088125	0.03083103	0.03077306	0.03071141
19	0.02191305	0.02226770	0.02249344	0.02269842	0.02288946
20	0.01940355	0.02022238	0.02111121	0.02205928	0.02305913

NBAR=	18	19	20
SIGMA=			
	1.03291339	1.03164884	1.03046401
0	0.71668040	0.71621236	0.71580599
1	0.70709712	0.70559125	0.70417923
2	0.68918703	0.68728354	0.68548799
3	0.66583402	0.66476005	0.66376024
4	0.62900366	0.62764060	0.62635614
5	0.58614433	0.58492794	0.58377958
6	0.53887674	0.53825740	0.53768141
7	0.48415079	0.48331420	0.48251361
8	0.42932021	0.42885130	0.42840823
9	0.37378115	0.37368005	0.37358623
10	0.31723577	0.31693137	0.31663719
11	0.26569854	0.26583719	0.26596833
12	0.21658395	0.21680256	0.21700899
13	0.17147649	0.17152633	0.17156603
14	0.13372833	0.13418325	0.13461538
15	0.09943290	0.09966852	0.09988904
16	0.07184950	0.07204071	0.07221522
17	0.05013183	0.05064941	0.05114427
18	0.03064950	0.03058962	0.03053310
19	0.02307172	0.02324628	0.02341191
20	0.02410447	0.02519126	0.02631567

DB=65

A= 2.60267633

NBAR=	10	11	12	13	14
SIGMA=	1.04022518	1.03964447	1.03867911	1.03751925	1.03627546
0	0.78393278	0.78321089	0.78185364	0.78039825	0.77860188
1	0.77728462	0.77655205	0.77526812	0.77376097	0.77209236
2	0.75763192	0.75690688	0.75574130	0.75424924	0.75272052
3	0.72584049	0.72518477	0.72409123	0.72277994	0.72131359
4	0.68330766	0.68275052	0.68176935	0.68062225	0.67936181
5	0.63186810	0.63139471	0.63060399	0.62960173	0.62857038
6	0.57366006	0.57327372	0.57265434	0.57189041	0.57102887
7	0.51098805	0.51071565	0.51023749	0.50969633	0.50909343
8	0.44620124	0.44603783	0.44573951	0.44535660	0.44498300
9	0.38156947	0.38148191	0.38135647	0.38117713	0.38095367
10	0.31914545	0.31912628	0.31910242	0.31910401	0.31908953
11	0.26064873	0.26070599	0.26077526	0.26085759	0.26098176
12	0.20741871	0.20752494	0.20770263	0.20788672	0.20806082
13	0.16041350	0.16052808	0.16074364	0.16102466	0.16131472
14	0.12018131	0.12030610	0.12050648	0.12076390	0.12107582
15	0.08680453	0.08695322	0.08718498	0.08743692	0.08768850
16	0.05995033	0.06008732	0.06033421	0.06064065	0.06096016
17	0.03913874	0.03922180	0.03937407	0.03958444	0.03984629
18	0.02410492	0.02416552	0.02424935	0.02433028	0.02440020
19	0.01494535	0.01504654	0.01521319	0.01541565	0.01561956
20	0.01188016	0.01201359	0.01226164	0.01259488	0.01299387

NBAR=	15	16	17	18	19
SIGMA=	1.03501123	1.03376398	1.03255427	1.03139401	1.03028795
0	0.77740823	0.77625282	0.77516254	0.77414032	0.77318360
1	0.77044152	0.76880752	0.76721798	0.76568926	0.76422837
2	0.75094595	0.74917367	0.74743420	0.74574938	0.74413020
3	0.71999719	0.71869858	0.71744264	0.71624049	0.71509594
4	0.67801877	0.67668481	0.67538046	0.67412061	0.67291237
5	0.62742726	0.62628396	0.62516318	0.62407364	0.62303694
6	0.57028500	0.56955358	0.56884694	0.56817082	0.56752706
7	0.50838512	0.50767608	0.50697709	0.50629740	0.50564188
8	0.44457964	0.44417266	0.44377293	0.44338534	0.44301221
9	0.38082201	0.38069780	0.38058015	0.38046899	0.38036396
10	0.31897062	0.31884247	0.31870848	0.31857222	0.31843606
11	0.26113666	0.26128917	0.26143887	0.26158356	0.26172212
12	0.20829454	0.20853162	0.20876393	0.20898838	0.20920347
13	0.16151411	0.16170076	0.16187524	0.16203751	0.16218820
14	0.12145743	0.12184262	0.12222352	0.12259447	0.12295246
15	0.08796076	0.08823242	0.08849634	0.08874998	0.08899225
16	0.06121017	0.06144910	0.06167739	0.06189376	0.06209812
17	0.04019663	0.04055803	0.04091970	0.04127544	0.04162157
18	0.02445011	0.02447652	0.02453950	0.02457963	0.02461753
19	0.01577394	0.01592442	0.01607138	0.01621541	0.01635589
20	0.01344569	0.01394097	0.01447323	0.01503720	0.01562940

NBAR= 20

SIGMA=

1.02923822

0	0.77228857
1	0.74283866
2	0.74258312
3	0.71401032
4	0.67175977
5	0.62204191
6	0.56691625
7	0.50501360
8	0.44265495
9	0.38026465
10	0.31830181
11	0.26185390
12	0.20940834
13	0.16232814
14	0.12329555
15	0.08922266
16	0.06229071
17	0.04195555
18	0.02465362
19	0.01649133
20	0.01624672



DR=70

A= 2.78591025

NBAR= 11

12

13

14

15

SIGMA=

	1.03528610	1.03501020	1.03439152	1.03357951	1.03266479
0	0.83929290	0.83888947	0.83803749	0.83681989	0.83571767
1	0.83160512	0.83131797	0.83035678	0.82920019	0.82791183
2	0.80891696	0.80856053	0.80772669	0.80665568	0.80534832
3	0.77232780	0.77199955	0.77126015	0.77026119	0.76920688
4	0.72358044	0.72329188	0.72265180	0.72179538	0.72079990
5	0.66493431	0.66470214	0.66416165	0.66346620	0.66263799
6	0.59901169	0.59883388	0.59842625	0.59787195	0.59730206
7	0.52862390	0.52849463	0.52821416	0.52783488	0.52736433
8	0.45658216	0.45650626	0.45632739	0.45610618	0.45584511
9	0.38552316	0.38549643	0.38542664	0.38532240	0.38524587
10	0.31777452	0.31778052	0.31780389	0.31782784	0.31780963
11	0.25524316	0.25527592	0.25534993	0.25546176	0.25560015
12	0.19932353	0.19938158	0.19950275	0.19965378	0.19984956
13	0.15087533	0.15094260	0.15110118	0.15130542	0.15149511
14	0.11027430	0.11033810	0.11048781	0.11069944	0.11096638
15	0.07744001	0.07750586	0.07764604	0.07782431	0.07803391
16	0.05183161	0.05189570	0.05204286	0.05223293	0.05241563
17	0.03260505	0.03264808	0.03275389	0.03290732	0.03311663
18	0.01902743	0.01905341	0.01910633	0.01917050	0.01923495
19	0.01083109	0.01086709	0.01094681	0.01104818	0.01114040
20	0.00809126	0.00813885	0.00825648	0.00842680	0.00863832

NBAR= 16

17

18

19

20

SIGMA=

	1.03170413	1.03073217	1.02977116	1.02883372	1.02792785
0	0.83455919	0.83339351	0.83224650	0.83113186	0.83005797
1	0.82655112	0.82516771	0.82379412	0.82244919	0.82114528
2	0.80396298	0.80254880	0.80113991	0.79975653	0.79841225
3	0.76809369	0.76696432	0.76584496	0.76475058	0.76369075
4	0.71974723	0.71867415	0.71760620	0.71655839	0.71554078
5	0.66175866	0.66086095	0.65996645	0.65908791	0.65823388
6	0.59670073	0.59609042	0.59548512	0.59489281	0.59431873
7	0.52686450	0.52635213	0.52583973	0.52533481	0.52484257
8	0.45556546	0.45527889	0.45499234	0.45470988	0.45443436
9	0.38516643	0.38508605	0.38500625	0.38492792	0.38485162
10	0.31778642	0.31775873	0.31772769	0.31769422	0.31765914
11	0.25574504	0.25589231	0.25603831	0.25618094	0.25631880
12	0.20005833	0.20027087	0.20048199	0.20069866	0.20089889
13	0.15169155	0.15188855	0.15208189	0.15226928	0.15244937
14	0.11125071	0.11154213	0.11183335	0.11212002	0.11239914
15	0.07825660	0.07848313	0.07870821	0.07892876	0.07914274
16	0.05260573	0.05279790	0.05298783	0.05317314	0.05335235
17	0.03334311	0.03357742	0.03381351	0.03404758	0.03427692
18	0.01930259	0.01937101	0.01943865	0.01950538	0.01957013
19	0.01123788	0.01133817	0.01143981	0.01154132	0.01164111
20	0.008080291	0.00915492	0.00944991	0.00976489	0.01009728

DB=75

A= 2.96914416

NBAR= 12 13 14 15 16

SIGMA=

	1.03113440	1.03108212	1.03072333	1.03017631	1.02951776
0	0.89483211	0.89475453	0.89419253	0.89342918	0.89250316
1	0.88602992	0.88595261	0.88541217	0.88458987	0.88359279
2	0.86009163	0.86001765	0.85951537	0.85870941	0.85773141
3	0.81837506	0.81830949	0.81784970	0.81717116	0.81634779
4	0.76301640	0.76296026	0.76256865	0.76195788	0.76121710
5	0.69677667	0.69673053	0.69641621	0.69591860	0.69531362
6	0.62283128	0.62279709	0.62255609	0.62220668	0.62178246
7	0.54452970	0.54450700	0.54434732	0.54406720	0.54377089
8	0.46517235	0.46515931	0.46507313	0.46493671	0.46476948
9	0.38780045	0.38779673	0.38776783	0.38773837	0.38770257
10	0.31500728	0.31501121	0.31503647	0.31505891	0.31508481
11	0.24882064	0.24882908	0.24889134	0.24899099	0.24911093
12	0.19064519	0.19065706	0.19073687	0.19086850	0.19102866
13	0.14122912	0.14124316	0.14133884	0.14147087	0.14162982
14	0.10070976	0.10072300	0.10081834	0.10097445	0.10116435
15	0.06873750	0.06874943	0.06883035	0.06895770	0.06911284
16	0.04454247	0.04455376	0.04463061	0.04473702	0.04486535
17	0.02700142	0.02700961	0.02706990	0.02717505	0.02730427
18	0.01498177	0.01498631	0.01501647	0.01506019	0.01511344
19	0.00783812	0.00784320	0.00787724	0.00792158	0.00797586
20	0.00545689	0.00546554	0.00551522	0.00559780	0.00570623

NBAR= 17 18 19 20

SIGMA=

	1.02879676	1.02804640	1.02728736	1.02653386
0	0.89148679	0.89042704	0.88935333	0.88828596
1	0.88249452	0.88134547	0.88017776	0.87901391
2	0.85665237	0.85552176	0.85437124	0.85322313
3	0.81544139	0.81449360	0.81353086	0.81257164
4	0.76039999	0.75954396	0.75867294	0.75780377
5	0.69464568	0.69394538	0.69323228	0.69252022
6	0.62131499	0.62082565	0.62032801	0.61983161
7	0.54342067	0.54305241	0.54267642	0.54230003
8	0.46458402	0.46438870	0.46418897	0.46398868
9	0.38766273	0.38762051	0.38757703	0.38753307
10	0.31511166	0.31513808	0.31516333	0.31518704
11	0.24924271	0.24938018	0.24951945	0.24965782
12	0.19120498	0.19138930	0.19157644	0.19176275
13	0.14180405	0.14198553	0.14216920	0.14235161
14	0.10137431	0.10159473	0.10181939	0.10204391
15	0.06928396	0.06946324	0.06964568	0.06982778
16	0.04500665	0.04515446	0.04530470	0.04545453
17	0.02744808	0.02759999	0.02775574	0.02791220
18	0.01517228	0.01523408	0.01529717	0.01536035
19	0.00803656	0.00810137	0.00816847	0.00823629
20	0.00583561	0.00596218	0.00614337	0.00631708

DB=80

A= 3.15337805

NBAR= 14

15

16

17

18

SIGMA=

	1.02771111	1.02754903	1.02720733	1.02675004	1.02622131
0	0.95070064	0.95045045	0.94991767	0.94920028	0.94836665
1	0.94070580	0.94044770	0.93989911	0.93915969	0.93829950
2	0.91128666	0.91103915	0.91051311	0.90980376	0.90897800
3	0.86409397	0.86389117	0.86342837	0.86281808	0.86210813
4	0.80172565	0.80154014	0.80114584	0.80061399	0.79999478
5	0.72750705	0.72735887	0.72704349	0.72661779	0.72612194
6	0.64522184	0.64511777	0.64489616	0.64459709	0.64424878
7	0.55882067	0.55874936	0.55859761	0.55839237	0.55815277
8	0.47212606	0.47209173	0.47201811	0.47191831	0.47180150
9	0.38857372	0.38857061	0.38856381	0.38855423	0.38854261
10	0.31101369	0.31102873	0.31106043	0.31110255	0.31115084
11	0.24156788	0.24160232	0.24167515	0.24177306	0.24188667
12	0.18157388	0.18161662	0.18170758	0.18183004	0.18197239
13	0.13160963	0.13165244	0.13174325	0.13186545	0.13200741
14	0.09155473	0.09160004	0.09169644	0.09182657	0.09197825
15	0.06072861	0.06076584	0.06084527	0.06095249	0.06107743
16	0.03806912	0.03809907	0.03816266	0.03824852	0.03834858
17	0.02222157	0.02224800	0.02230455	0.02238123	0.02247098
18	0.01174958	0.01176228	0.01178947	0.01182634	0.01186947
19	0.00565958	0.00566998	0.00569235	0.00572300	0.00575933
20	0.00364246	0.00365858	0.00369527	0.00374830	0.00381453

NBAR= 19

20

SIGMA=

	1.02565017	1.02505730
0	0.94746252	0.94652062
1	0.93736547	0.93639128
2	0.90808081	0.90714451
3	0.86133724	0.86053323
4	0.79932184	0.79861940
5	0.72558275	0.72501965
6	0.64387011	0.64347468
7	0.55789164	0.55761832
8	0.47167389	0.47153998
9	0.38852948	0.38851522
10	0.31120250	0.31125557
11	0.24200974	0.24213774
12	0.18212682	0.18228773
13	0.13216133	0.13232164
14	0.09214326	0.09231567
15	0.06121334	0.06135531
16	0.03845743	0.03857116
17	0.02256906	0.02267198
18	0.01191654	0.01196590
19	0.00579946	0.00584180
20	0.00389174	0.00397620

### A P P E N D I X 3

#### BAYLISS WEIGHTING FUNCTION TABLES

In this appendix a table is presented of the Bayliss weighting function for a circular antenna aperture.

In this table the design side lobe level is shown as the parameter, DB. The parameter A is derived from DB by using the following expression:

$$A = 1/\pi \cosh^{-1}[10.0^{DB/20}]$$

For each value of NBAR the beam spread factor, SIGMA, and the associated sampled weighting function are tabulated. In this table 20 samples were taken across the radius of the aperture. The number of samples is user defined and can be changed to give either finer or more coarse sampling. In preparing this table the values of N which were not allowable were omitted. The minimum allowable value of N is a function of the design side lobe level.

DB=20

A= 0.95277244

NBAK= 3 4 5 6 7

SIGMA=  
1.14746191 1.13040048 1.12663190 1.10891059 1.09540489

0	0.	0.	0.	0.	0.
1	-0.04180987	-0.04068073	-0.03272988	-0.03823956	-0.01057190
2	-0.08226165	-0.07977445	-0.06575164	-0.07296831	-0.03271236
3	-0.12007115	-0.11581995	-0.09895842	-0.10216770	-0.06964737
4	-0.15409746	-0.14759379	-0.13158626	-0.12600714	-0.11384739
5	-0.18340354	-0.17419677	-0.16219218	-0.14636755	-0.15219288
6	-0.20730446	-0.19510634	-0.18888901	-0.16544187	-0.17491475
7	-0.22540016	-0.21019077	-0.20977508	-0.18416413	-0.18184015
8	-0.23759115	-0.21968614	-0.22343302	-0.20133513	-0.19151942
9	-0.24407592	-0.22414125	-0.22934662	-0.21397358	-0.19406263
10	-0.24533077	-0.22433949	-0.22810619	-0.21879218	-0.19313425
11	-0.24207311	-0.22120852	-0.22133417	-0.21409599	-0.20316332
12	-0.23521099	-0.21572920	-0.21134537	-0.20113525	-0.20396469
13	-0.22578186	-0.20885408	-0.20063458	-0.18416258	-0.18943805
14	-0.21488473	-0.20144291	-0.19133445	-0.16905003	-0.16384882
15	-0.20360998	-0.19421951	-0.18479366	-0.16102319	-0.14074374
16	-0.19297108	-0.18775050	-0.18138736	-0.16252385	-0.13476167
17	-0.18384282	-0.18244298	-0.18060115	-0.17219056	-0.15176541
18	-0.17690948	-0.17855595	-0.18134839	-0.18545165	-0.18414103
19	-0.17262635	-0.17621896	-0.18241332	-0.19648957	-0.21473338
20	-0.17119671	-0.17545171	-0.18287948	-0.20070804	-0.22704867

NBAR= 8 9 10 11 12

SIGMA=  
1.08481491 1.07630727 1.06933174 1.06351329 1.05858862

0	0.	0.	0.	0.	0.
1	-0.03840766	-0.00435041	-0.03808233	-0.00122493	-0.03706469
2	-0.06477068	-0.02982879	-0.05401372	-0.03351501	-0.04263494
3	-0.07959206	-0.07282682	-0.06064690	-0.07555938	-0.05187553
4	-0.09515465	-0.11086834	-0.08507405	-0.09603788	-0.09029388
5	-0.12197212	-0.13052519	-0.12532618	-0.10826036	-0.12221461
6	-0.15649569	-0.14120843	-0.15329717	-0.13638863	-0.13042646
7	-0.18327332	-0.15822161	-0.15805993	-0.16392970	-0.14551913
8	-0.19008240	-0.17934312	-0.15954738	-0.16556927	-0.16726371
9	-0.18081670	-0.18751105	-0.17213461	-0.15759478	-0.16463601
10	-0.17237477	-0.17647367	-0.18047815	-0.16555237	-0.15263846
11	-0.17765939	-0.16355229	-0.16930523	-0.17366079	-0.16196257
12	-0.19146643	-0.16876304	-0.15621601	-0.16057481	-0.16757073
13	-0.19441254	-0.18522131	-0.16579068	-0.15101681	-0.15022574
14	-0.17277986	-0.18221748	-0.18093589	-0.16778068	-0.15107253
15	-0.13567331	-0.14397734	-0.15773758	-0.16762219	-0.16767882
16	-0.11170510	-0.09889327	-0.09830736	-0.10810981	-0.12353464
17	-0.12582973	-0.09830669	-0.07328799	-0.05433169	-0.04383813
18	-0.17609396	-0.16135866	-0.14063939	-0.11515118	-0.08650033
19	-0.23167315	-0.24644777	-0.25845229	-0.26720886	-0.27233603
20	-0.25541205	-0.28535400	-0.31667468	-0.34925553	-0.38301574

NBAR= 13 14 15 16 17

SIGMA=

1.05436802 1.05071145 1.04751351 1.04469343 1.04218817

	0.	0.	0.	0.	0.
0	0.	0.	0.	0.	0.
1	-0.00019609	-0.03569476	-0.01287433	0.01040602	0.02562440
2	-0.03928935	-0.03277421	-0.04024003	-0.05096000	-0.05781596
3	-0.07091751	-0.05320225	-0.05684140	-0.05659904	-0.05618275
4	-0.07949854	-0.09319822	-0.08065226	-0.06976287	-0.06221182
5	-0.10747901	-0.10527246	-0.11059815	-0.11937528	-0.12481814
6	-0.14038631	-0.12440171	-0.12275942	-0.11543138	-0.11014531
7	-0.14473275	-0.15234536	-0.14231375	-0.13685546	-0.13248684
8	-0.15056682	-0.15007738	-0.15513230	-0.16166695	-0.16581389
9	-0.16644789	-0.15172164	-0.14700241	-0.13646926	-0.12888431
10	-0.15807837	-0.16309551	-0.15573670	-0.15528520	-0.15406407
11	-0.14797229	-0.14872995	-0.15398770	-0.15768050	-0.16045855
12	-0.16233955	-0.14823338	-0.14064441	-0.12895217	-0.12008953
13	-0.15830557	-0.16235627	-0.15801607	-0.16142073	-0.16283161
14	-0.14118177	-0.14255586	-0.14794594	-0.14886620	-0.15048688
15	-0.15792963	-0.14354329	-0.13239649	-0.12009591	-0.10972177
16	-0.13862886	-0.14823685	-0.15159614	-0.16083742	-0.16706074
17	-0.04269276	-0.05029004	-0.06173415	-0.06662710	-0.07300076
18	-0.05653933	-0.02713133	-0.00127208	0.01964416	0.03796622
19	-0.27354271	-0.27056591	-0.26502937	-0.26567152	-0.26480268
20	-0.41789471	-0.45384468	-0.49082606	-0.52880447	-0.56775054

NBAR= 18 19

SIGMA=

1.03994803 1.03793314

	0.	0.
0	0.	0.
1	0.04003520	0.05348123
2	-0.06431041	-0.07037668
3	-0.05592510	-0.05575542
4	-0.05510047	-0.04850296
5	-0.13003820	-0.13493884
6	-0.10534381	-0.10097743
7	-0.12837797	-0.12458520
8	-0.16986157	-0.17367448
9	-0.12190268	-0.11552639
10	-0.15290609	-0.15183723
11	-0.16324907	-0.16589803
12	-0.11190125	-0.10444163
13	-0.16411666	-0.16525431
14	-0.15220664	-0.15388648
15	-0.10014918	-0.09145838
16	-0.17243416	-0.17702399
17	-0.07905940	-0.08469674
18	0.05375468	0.06732371
19	-0.26426301	-0.26405616
20	-0.60763703	-0.64844030

DR=25

A= 1.13655318

NBAR= 3 4 5 6 7

SIGMA=  
1.11726178 1.11251612 1.11837471 1.10318682 1.09121516

0	0.	0.	0.	0.	0.
1	-0.05754114	-0.05270357	-0.05397997	-0.05134711	-0.03291442
2	-0.11296501	-0.10381367	-0.10632078	-0.10041886	-0.07279838
3	-0.16427243	-0.15178262	-0.15543776	-0.14543999	-0.12114170
4	-0.20969308	-0.19515808	-0.19985522	-0.18538913	-0.17231307
5	-0.24778231	-0.23263871	-0.23826125	-0.21988985	-0.21687070
6	-0.27749797	-0.26313624	-0.26956280	-0.24881532	-0.24744207
7	-0.29825267	-0.28584092	-0.29294083	-0.27183831	-0.26302116
8	-0.30993847	-0.30028506	-0.30790407	-0.28619453	-0.26873888
9	-0.31292246	-0.30639643	-0.31433784	-0.29682278	-0.27145065
10	-0.30801396	-0.30453297	-0.31254222	-0.29684998	-0.27447628
11	-0.29640550	-0.29549018	-0.30325180	-0.28620169	-0.27537205
12	-0.27959147	-0.28047482	-0.28762815	-0.27203339	-0.26834731
13	-0.25926975	-0.26104210	-0.26721728	-0.25074229	-0.24951428
14	-0.23723270	-0.23899762	-0.24386740	-0.22750510	-0.22106242
15	-0.21525432	-0.21627036	-0.21960757	-0.20550571	-0.19118504
16	-0.19498072	-0.19476690	-0.19649460	-0.18716264	-0.16962122
17	-0.17783086	-0.17622075	-0.17644196	-0.17366862	-0.16182582
18	-0.16491337	-0.16205175	-0.16104968	-0.16501134	-0.16579589
19	-0.15696482	-0.15325035	-0.15145649	-0.16042539	-0.17375134
20	-0.15431268	-0.15029930	-0.14823410	-0.15903396	-0.17750663

NBAR= 8 9 10 11 12

SIGMA=  
1.08162032 1.07379328 1.06730300 1.06184234 1.05718888

0	0.	0.	0.	0.	0.
1	-0.04940859	-0.02619006	-0.04789395	-0.02239269	-0.04631866
2	-0.09081476	-0.06610880	-0.08072604	-0.06566783	-0.07087355
3	-0.12403348	-0.11692632	-0.10666071	-0.11495981	-0.09733386
4	-0.15609859	-0.16299238	-0.14309277	-0.14826335	-0.14247888
5	-0.19265260	-0.19433050	-0.18771235	-0.17359928	-0.18094970
6	-0.23030208	-0.21604016	-0.22065056	-0.20640053	-0.19996761
7	-0.25831084	-0.23749396	-0.23381117	-0.23482200	-0.21979290
8	-0.26856349	-0.25709929	-0.24033130	-0.24144820	-0.24013738
9	-0.26392651	-0.26399765	-0.25026846	-0.23759001	-0.23999491
10	-0.25611496	-0.25474411	-0.25411881	-0.24132351	-0.23024981
11	-0.25442798	-0.24150614	-0.24234130	-0.24278477	-0.23270534
12	-0.25624483	-0.23813770	-0.22715903	-0.22792505	-0.23084104
13	-0.24923349	-0.24047572	-0.22532760	-0.21355323	-0.21149860
14	-0.22414626	-0.22817773	-0.22556164	-0.21524156	-0.20266719
15	-0.18633834	-0.19035729	-0.19827721	-0.20387009	-0.20299882
16	-0.15439227	-0.14545785	-0.14448158	-0.15049326	-0.16041560
17	-0.14581527	-0.12818327	-0.11174046	-0.09901930	-0.09181171
18	-0.16207028	-0.15365524	-0.14090474	-0.12458491	-0.10577160
19	-0.18653545	-0.19802754	-0.20770957	-0.21517994	-0.22012068
20	-0.19777394	-0.21940428	-0.24218929	-0.26600354	-0.29076248

NBAR= 13 14 15 16 17

SIGMA=

	1.05317864	1.04968847	1.04662442	1.04391359	1.04149868
0	0.	0.	0.	0.	0.
1	-0.02052752	-0.04472941	-0.02851177	-0.01196187	-0.00105699
2	-0.06771210	-0.06246794	-0.06702994	-0.07396317	-0.07827353
3	-0.10918339	-0.09584978	-0.09746293	-0.09648568	-0.09547839
4	-0.13347867	-0.14160879	-0.13169750	-0.12306186	-0.11686794
5	-0.16897536	-0.16587364	-0.16821308	-0.17314534	-0.17589693
6	-0.20480435	-0.19200788	-0.18936997	-0.18293674	-0.17806995
7	-0.21716050	-0.22062692	-0.21207332	-0.20688686	-0.20261464
8	-0.22653664	-0.22439616	-0.22634525	-0.22952987	-0.23121248
9	-0.23919168	-0.22723590	-0.22243044	-0.21373456	-0.20723468
10	-0.23206705	-0.23387287	-0.22729603	-0.22571013	-0.22373329
11	-0.22131197	-0.22031785	-0.22264823	-0.22405252	-0.22495594
12	-0.22564958	-0.21451960	-0.20806268	-0.19885971	-0.19172828
13	-0.21573351	-0.21737440	-0.21333194	-0.21481971	-0.21502325
14	-0.19487774	-0.19496796	-0.19794532	-0.19788579	-0.19838962
15	-0.19554729	-0.18497909	-0.17671322	-0.16767210	-0.15999389
16	-0.17023531	-0.17639071	-0.17831200	-0.18443430	-0.18852631
17	-0.09086920	-0.09589630	-0.10358278	-0.10670914	-0.11089944
18	-0.08574767	-0.06582938	-0.04813972	-0.03370522	-0.02093077
19	-0.22228774	-0.22146485	-0.21875421	-0.22025285	-0.22059871
20	-0.31640474	-0.34288326	-0.37015997	-0.39820361	-0.42698728

NBAR= 18 19

SIGMA=

	1.03933407	1.03738298
0	0.	0.
1	0.00929328	0.01898586
2	-0.08240486	-0.08630300
3	-0.09466048	-0.09397130
4	-0.11106442	-0.10568697
5	-0.17862667	-0.18124999
6	-0.17365638	-0.16964303
7	-0.19864869	-0.19500802
8	-0.23297336	-0.23469835
9	-0.20126550	-0.19581026
10	-0.22192399	-0.22028143
11	-0.22599085	-0.22703352
12	-0.18514162	-0.17912529
13	-0.21523319	-0.21542048
14	-0.19903127	-0.19970666
15	-0.15288364	-0.14639525
16	-0.19208868	-0.19515400
17	-0.11490516	-0.11865277
18	-0.00981113	-0.00015734
19	-0.22108857	-0.22173530
20	-0.45648734	-0.48668348



DB=30

A= 1.31995942

NBAR= 5 6 7 8 9

SIGMA=

1.10891379 1.09658253 1.08635993 1.07790771 1.07086584

0	0.	0.	0.	0.	0.
1	-0.07631211	-0.06939738	-0.05705892	-0.06548036	-0.04989391
2	-0.14938456	-0.13658328	-0.11724180	-0.12517200	-0.10753759
3	-0.21630525	-0.19935612	-0.18029189	-0.17788601	-0.17016092
4	-0.27474264	-0.25558125	-0.24154834	-0.22663168	-0.22675660
5	-0.32307300	-0.30331440	-0.29399646	-0.27350269	-0.26976975
6	-0.36036867	-0.34097104	-0.33198184	-0.31526357	-0.30125348
7	-0.38627633	-0.36748973	-0.35405887	-0.34462947	-0.32639989
8	-0.40084573	-0.38243247	-0.36310026	-0.35649656	-0.34414172
9	-0.40437994	-0.38598998	-0.36373575	-0.35305578	-0.34813605
10	-0.39736589	-0.37890191	-0.35903077	-0.34237738	-0.33700189
11	-0.38051024	-0.36233906	-0.34876803	-0.33124806	-0.31926738
12	-0.35486404	-0.33780749	-0.33047456	-0.31907292	-0.30451448
13	-0.32198114	-0.30711279	-0.30234578	-0.29895040	-0.29088864
14	-0.28403492	-0.27237936	-0.26588435	-0.26547794	-0.26609747
15	-0.24382144	-0.23607362	-0.22631897	-0.22212378	-0.22351646
16	-0.20460496	-0.20095816	-0.19047834	-0.18095597	-0.17508094
17	-0.16980622	-0.16991995	-0.16358993	-0.15436794	-0.14378105
18	-0.14258116	-0.14566496	-0.14717569	-0.14590717	-0.14156663
19	-0.12537499	-0.13033412	-0.13936906	-0.14836595	-0.15670198
20	-0.11955010	-0.12514269	-0.13723272	-0.15083983	-0.16557417

NBAR= 10 11 12 13 14

SIGMA=

1.06493725 1.05989175 1.05555356 1.05178821 1.04849198

0	0.	0.	0.	0.	0.
1	-0.06268334	-0.04547940	-0.06036776	-0.04287494	-0.05836328
2	-0.11492044	-0.10366911	-0.10574208	-0.10254333	-0.09811475
3	-0.16095070	-0.16403879	-0.15067969	-0.15683687	-0.14663373
4	-0.21074872	-0.21125569	-0.20510816	-0.19717444	-0.20078734
5	-0.26166041	-0.24933011	-0.25136485	-0.24115820	-0.23708632
6	-0.29994411	-0.28724704	-0.28009082	-0.28071532	-0.27006008
7	-0.31971743	-0.31673250	-0.30388406	-0.29953739	-0.29955195
8	-0.32922075	-0.32636297	-0.32247161	-0.31095126	-0.30729856
9	-0.33534593	-0.32379159	-0.32248091	-0.31947630	-0.30943799
10	-0.33286628	-0.32150566	-0.31166857	-0.31060418	-0.30982650
11	-0.31653282	-0.31406297	-0.30516371	-0.29569492	-0.29331600
12	-0.29484176	-0.29305484	-0.29298789	-0.28788008	-0.27906188
13	-0.27913955	-0.26979041	-0.26694711	-0.26840461	-0.26831459
14	-0.26286052	-0.25491056	-0.24564754	-0.23962456	-0.23888461
15	-0.22755766	-0.23029025	-0.22897949	-0.22347227	-0.21598713
16	-0.17412422	-0.17763143	-0.18371073	-0.18978372	-0.19350990
17	-0.13364512	-0.12566390	-0.12109061	-0.12050355	-0.12378193
18	-0.13427950	-0.12448810	-0.11287172	-0.10027070	-0.08756574
19	-0.16395153	-0.16979161	-0.17397018	-0.17629419	-0.17659616
20	-0.18123408	-0.19769632	-0.21487859	-0.23272227	-0.25118357

NBAR=	15	16	17	18	19
SIGMA=	1.04558408	1.04300080	1.04069141	1.03861506	1.03673854
0	0.	0.	0.	0.	0.
1	-0.04715452	-0.03575943	-0.02816723	-0.02096322	-0.01420612
2	-0.10030224	-0.10417429	-0.10638363	-0.10855310	-0.11063810
3	-0.14649501	-0.14477641	-0.14315498	-0.14176014	-0.14053708
4	-0.19267119	-0.18557585	-0.18025671	-0.17531681	-0.17075937
5	-0.23697071	-0.23259216	-0.23903530	-0.23961880	-0.24026658
6	-0.26639407	-0.26042146	-0.25567498	-0.25138221	-0.24748456
7	-0.29188257	-0.28667989	-0.28227875	-0.27824159	-0.27455646
8	-0.30663031	-0.30701359	-0.30658744	-0.30638199	-0.30629916
9	-0.30438621	-0.29695312	-0.29115679	-0.28585641	-0.28101847
10	-0.30373173	-0.30115495	-0.29848432	-0.29606690	-0.29388160
11	-0.29334545	-0.29292960	-0.29232535	-0.29193715	-0.29166631
12	-0.27350336	-0.26625124	-0.26049032	-0.25518146	-0.25032737
13	-0.26459288	-0.26466880	-0.26398928	-0.26340195	-0.26287558
14	-0.24013780	-0.23943796	-0.23917648	-0.23906510	-0.23902903
15	-0.21007936	-0.20368963	-0.19623047	-0.19316343	-0.18852099
16	-0.19449431	-0.19833403	-0.20086910	-0.20309219	-0.20501712
17	-0.12878936	-0.13074986	-0.13342473	-0.13598899	-0.13839654
18	-0.07618477	-0.06684009	-0.05849443	-0.05116668	-0.04475006
19	-0.17558781	-0.17732112	-0.17822557	-0.17917080	-0.18017076
20	-0.27022821	-0.28982851	-0.30996158	-0.33060763	-0.35174996

DB=35

A= 1.50324775

NBAR= 5 6 7 8 9

SIGMA=

1.09833834 1.08914168 1.09086269 1.07369046 1.06753293

0	0.	0.	0.	0.	0.
1	-0.10054630	-0.09207351	-0.08350874	-0.08657594	-0.07589462
2	-0.19633840	-0.18111148	-0.16689306	-0.16805755	-0.15482134
3	-0.28312135	-0.26393624	-0.24610510	-0.24195902	-0.23343001
4	-0.35753096	-0.33725826	-0.32263006	-0.30820619	-0.30338044
5	-0.41730149	-0.39795357	-0.38476244	-0.36633148	-0.35851760
6	-0.46126674	-0.44351960	-0.42990860	-0.41314802	-0.39882370
7	-0.48919017	-0.47252677	-0.45644028	-0.44370769	-0.42677052
8	-0.50150515	-0.48486232	-0.46594613	-0.45503541	-0.44176550
9	-0.49906437	-0.48164730	-0.46181381	-0.44908521	-0.44065177
10	-0.48298371	-0.46485896	-0.44716589	-0.43176177	-0.42366794
11	-0.45462368	-0.43683092	-0.42353026	-0.40852016	-0.39723725
12	-0.41569665	-0.39986124	-0.39104029	-0.38049981	-0.36849349
13	-0.36843626	-0.35609944	-0.34987327	-0.34491763	-0.33760916
14	-0.31573553	-0.30773620	-0.30181412	-0.29956628	-0.29824395
15	-0.26116096	-0.25735294	-0.25081807	-0.24733391	-0.24724446
16	-0.20878210	-0.20818889	-0.20219568	-0.19645533	-0.19271628
17	-0.16281104	-0.16410203	-0.16099917	-0.15602003	-0.15000263
18	-0.12710568	-0.12913254	-0.13063503	-0.13058145	-0.12863079
19	-0.10463767	-0.10676524	-0.11249736	-0.11850870	-0.12428805
20	-0.09704580	-0.09914017	-0.10656569	-0.11527088	-0.12491388

NBAR= 10 11 12 13 14

SIGMA=

1.06223939 1.05766462 1.05368465 1.03019802 1.04712281

0	0.	0.	0.	0.	0.
1	-0.08253281	-0.07082102	-0.07937469	-0.06748597	-0.07680978
2	-0.15704100	-0.14809476	-0.14775615	-0.14429266	-0.14021267
3	-0.22451822	-0.22367075	-0.21287255	-0.21476615	-0.20643506
4	-0.28930322	-0.28636903	-0.27953719	-0.27193944	-0.27205260
5	-0.34888338	-0.33725587	-0.33517060	-0.32574953	-0.32060597
6	-0.39301353	-0.38086431	-0.37273166	-0.37000683	-0.36043600
7	-0.41759235	-0.41141816	-0.39961606	-0.39366688	-0.39090230
8	-0.42769065	-0.42172369	-0.41567482	-0.40522603	-0.40019385
9	-0.42821379	-0.41711476	-0.41295019	-0.40813761	-0.39916049
10	-0.41702384	-0.40645285	-0.39726125	-0.37400693	-0.39124732
11	-0.39208075	-0.38756812	-0.37939261	-0.37115211	-0.36770718
12	-0.35978935	-0.35630557	-0.35420849	-0.34915728	-0.34192809
13	-0.32832874	-0.32674436	-0.31744147	-0.31704647	-0.31580918
14	-0.29483023	-0.28866613	-0.28180418	-0.27709919	-0.27586588
15	-0.24891075	-0.24990159	-0.24845673	-0.24442402	-0.23918244
16	-0.19190870	-0.19386614	-0.19746738	-0.20110306	-0.20327586
17	-0.14406522	-0.13931237	-0.13659073	-0.13632428	-0.13848387
18	-0.12476644	-0.11921425	-0.11237995	-0.10479285	-0.09702299
19	-0.12948554	-0.13384090	-0.13715450	-0.13927441	-0.14007197
20	-0.13530409	-0.14632267	-0.15709049	-0.16995199	-0.18246636

NBAR=	15	16	17	18	19
SIGMA=	1.04439302	1.04195538	1.03976654	1.03779110	1.03599986
0	0.	0.	0.	0.	0.
1	-0.06899511	-0.061111435	-0.05575927	-0.05069179	-0.04593949
2	-0.14054644	-0.14209790	-0.14267192	-0.14331304	-0.14398160
3	-0.20479892	-0.20231270	-0.20003491	-0.19802917	-0.19624254
4	-0.26486073	-0.25854408	-0.25356523	-0.24898480	-0.24478093
5	-0.31824692	-0.31739376	-0.31591931	-0.31471980	-0.31372217
6	-0.35568415	-0.34969897	-0.34473184	-0.34024685	-0.33617867
7	-0.38350161	-0.37796806	-0.37318338	-0.36882871	-0.36486754
8	-0.39737926	-0.39551846	-0.39335297	-0.39152457	-0.38994447
9	-0.39368362	-0.38690108	-0.38138380	-0.37635828	-0.37177776
10	-0.38531254	-0.38187536	-0.37856149	-0.37557024	-0.37286594
11	-0.36603134	-0.36424721	-0.36249522	-0.36101992	-0.35974012
12	-0.33696969	-0.33105318	-0.32622355	-0.32178548	-0.31772610
13	-0.31235443	-0.31147350	-0.31019714	-0.30906466	-0.30804488
14	-0.27599172	-0.27491292	-0.27417581	-0.27358864	-0.27309776
15	-0.23500233	-0.23054040	-0.22670473	-0.22313857	-0.21985974
16	-0.20371946	-0.20605313	-0.20757027	-0.20891142	-0.21008063
17	-0.14172845	-0.14298032	-0.14469281	-0.14633563	-0.14788179
18	-0.09000350	-0.08421392	-0.07899627	-0.07437717	-0.07029972
19	-0.13999075	-0.14165220	-0.14273682	-0.14381195	-0.14488933
20	-0.19540247	-0.20873561	-0.22244620	-0.23651735	-0.25093546

DR=40

A= 1.68649887

NBAR= 5 6 7 8 9

SIGMA= 1.08674867 1.08091597 1.07475226 1.06898566 1.06380524

0	0.	0.	0.	0.	0.
1	-0.12746804	-0.11943076	-0.11328461	-0.11300453	-0.10530854
2	-0.24855252	-0.23431156	-0.22349673	-0.22041797	-0.20973797
3	-0.35750416	-0.34001137	-0.32664976	-0.31813068	-0.30878004
4	-0.44972188	-0.43193681	-0.41768677	-0.40353260	-0.39521014
5	-0.52205873	-0.50593246	-0.49133352	-0.47419137	-0.46342379
6	-0.57288695	-0.55887247	-0.54353670	-0.52682862	-0.51197069
7	-0.60195127	-0.58921676	-0.57266482	-0.55804509	-0.54166259
8	-0.61008861	-0.59728262	-0.57978471	-0.56645005	-0.55243120
9	-0.59891574	-0.58508770	-0.56789356	-0.55422228	-0.54350016
10	-0.57057772	-0.55580855	-0.54060685	-0.52638181	-0.51660433
11	-0.52761277	-0.51307255	-0.50107762	-0.48808511	-0.47737628
12	-0.47293726	-0.46037607	-0.45169876	-0.44217374	-0.43198992
13	-0.40990377	-0.40085320	-0.39459825	-0.38911991	-0.38253078
14	-0.34235308	-0.33744032	-0.33244697	-0.32939910	-0.32706961
15	-0.27457694	-0.27327780	-0.26896446	-0.26610537	-0.26521927
16	-0.21113454	-0.21206074	-0.20677256	-0.20537837	-0.20300789
17	-0.15651307	-0.15806385	-0.15668869	-0.15417434	-0.15092671
18	-0.11467588	-0.11571558	-0.11685938	-0.11726475	-0.11658325
19	-0.08858568	-0.08881597	-0.09213629	-0.09592554	-0.09976350
20	-0.07980827	-0.07967519	-0.08384907	-0.08911914	-0.09518922

NBAR= 10 11 12 13 14

SIGMA= 1.05921642 1.05516566 1.05158542 1.04841039 1.04556259

0	0.	0.	0.	0.	0.
1	-0.10782968	-0.09952162	-0.10376029	-0.09541249	-0.10050741
2	-0.20833268	-0.20056775	-0.19833575	-0.19440338	-0.19027920
3	-0.29964519	-0.29579946	-0.28624712	-0.28491877	-0.27744701
4	-0.38221852	-0.37619309	-0.36839826	-0.36053036	-0.35786658
5	-0.45229605	-0.44056355	-0.43522005	-0.42578529	-0.41943141
6	-0.50276467	-0.49041845	-0.48108599	-0.47561720	-0.46626206
7	-0.53043045	-0.52167494	-0.51004047	-0.50252990	-0.49744949
8	-0.53854193	-0.53012138	-0.52221388	-0.51203399	-0.50563170
9	-0.53104524	-0.51991472	-0.51352712	-0.50717427	-0.49856344
10	-0.50822138	-0.49795880	-0.48894647	-0.48399617	-0.47967950
11	-0.47063964	-0.46470771	-0.45687851	-0.44929896	-0.44499315
12	-0.42396976	-0.41937663	-0.41591409	-0.41084831	-0.40460671
13	-0.37496152	-0.36857389	-0.36499613	-0.36338846	-0.36158734
14	-0.32369360	-0.31679216	-0.31356074	-0.30976300	-0.30823273
15	-0.26548241	-0.26544921	-0.26400487	-0.26101122	-0.25730432
16	-0.20233291	-0.20333988	-0.20538739	-0.20749006	-0.20870347
17	-0.14760280	-0.14489819	-0.14337196	-0.14332624	-0.14477500
18	-0.11471582	-0.11174592	-0.10791089	-0.10351973	-0.09893562
19	-0.10335803	-0.10649493	-0.10901260	-0.11078908	-0.11173375
20	-0.10188036	-0.10907836	-0.11670687	-0.12471257	-0.13305697

NBAR= 15 16 17 18 19

SIGMA= 1.04305249 1.04077823 1.03872475 1.03686269 1.03516735

0	0.	0.	0.	0.	0.
1	-0.09482126	-0.08916019	-0.08518196	-0.08143672	-0.07793198
2	-0.18912625	-0.18889873	-0.18816924	-0.18759324	-0.18713231
3	-0.27446064	-0.27113762	-0.26812328	-0.26543504	-0.26301909
4	-0.35086773	-0.34467897	-0.33956573	-0.33489330	-0.33062157
5	-0.41518427	-0.41218911	-0.40904340	-0.40629082	-0.40385747
6	-0.46031825	-0.45389045	-0.44837509	-0.44339252	-0.43887085
7	-0.48978633	-0.48362075	-0.47819889	-0.47327906	-0.46880792
8	-0.50103449	-0.49731426	-0.49365109	-0.49042517	-0.48755205
9	-0.49246234	-0.48583189	-0.48021939	-0.47511697	-0.47046847
10	-0.47361847	-0.46938531	-0.46543250	-0.46186103	-0.45862547
11	-0.44203376	-0.43919564	-0.43654296	-0.43421320	-0.43213682
12	-0.39997461	-0.39487458	-0.39059447	-0.38667047	-0.38308016
13	-0.35811313	-0.35658396	-0.35489528	-0.35338151	-0.35201256
14	-0.30763520	-0.30632945	-0.30529744	-0.30441158	-0.30363257
15	-0.25430912	-0.25116260	-0.24843898	-0.24590426	-0.24356694
16	-0.20884773	-0.21022656	-0.21110469	-0.21188909	-0.21257887
17	-0.14689160	-0.14772195	-0.14884217	-0.14991654	-0.15092980
18	-0.09475770	-0.09130262	-0.08815947	-0.08535426	-0.08285883
19	-0.11208399	-0.11353805	-0.11459992	-0.11563326	-0.11664648
20	-0.14171096	-0.15065229	-0.15986323	-0.16932926	-0.17903839

DB=45

A= 1.86973822

NBAR= 5 6 7 8 9

SIGMA=  
1.07425098 1.07196186 1.06806086 1.06381285 1.05969520

0	0.	0.	0.	0.	0.
1	-0.15782680	-0.15201012	-0.14781509	-0.14569201	-0.13979262
2	-0.30737748	-0.29735223	-0.28960301	-0.28430249	-0.27512529
3	-0.44115431	-0.42947690	-0.41915655	-0.40968696	-0.39974835
4	-0.55308959	-0.54224494	-0.53027533	-0.51689482	-0.50634675
5	-0.63897415	-0.63045368	-0.61744056	-0.60180890	-0.58918028
6	-0.69661796	-0.69049658	-0.67676126	-0.66092625	-0.64574852
7	-0.72575733	-0.72092884	-0.70675949	-0.69192152	-0.67595700
8	-0.72777384	-0.72269538	-0.70859991	-0.69475762	-0.68042680
9	-0.70531841	-0.69888616	-0.68563800	-0.67233996	-0.66042106
10	-0.66193498	-0.65407151	-0.64249821	-0.62987496	-0.61931736
11	-0.60175340	-0.59344481	-0.58410079	-0.57313479	-0.56305859
12	-0.52927944	-0.52207676	-0.51502949	-0.50681533	-0.49803263
13	-0.44926706	-0.44452272	-0.43940348	-0.43415993	-0.42826339
14	-0.36662614	-0.36485067	-0.36113623	-0.35797098	-0.35520451
15	-0.28630760	-0.28695464	-0.28428697	-0.28196774	-0.28067284
16	-0.21312047	-0.21488408	-0.21321413	-0.21121306	-0.20965066
17	-0.15146620	-0.15291971	-0.15239044	-0.15120329	-0.14952444
18	-0.10501212	-0.10525848	-0.10592736	-0.10637243	-0.10626812
19	-0.07635887	-0.07537272	-0.07698265	-0.07916303	-0.08156896
20	-0.06677161	-0.06528184	-0.06724783	-0.07017034	-0.07379523

NBAR= 10 11 12 13 14

SIGMA=  
1.05587658 1.05240054 1.04925987 1.04642820 1.04387353

0	0.	0.	0.	0.	0.
1	-0.13960262	-0.13327565	-0.13457320	-0.12831384	-0.13049970
2	-0.27119737	-0.26385103	-0.26005365	-0.25546526	-0.25096967
3	-0.39013001	-0.38393214	-0.37468210	-0.37079018	-0.36339749
4	-0.49351437	-0.48512045	-0.47612551	-0.46749296	-0.46246597
5	-0.57671105	-0.56433885	-0.55628295	-0.54620051	-0.53844326
6	-0.63403409	-0.62100307	-0.61027316	-0.60239996	-0.59255847
7	-0.66311139	-0.65221347	-0.64010255	-0.63098545	-0.62382036
8	-0.66640903	-0.65600663	-0.64641066	-0.63587730	-0.62810732
9	-0.64780887	-0.63633273	-0.62812338	-0.62033534	-0.61155377
10	-0.60979123	-0.59951162	-0.59032275	-0.58396294	-0.57831897
11	-0.55534824	-0.54840531	-0.54061859	-0.53325109	-0.52816621
12	-0.49050279	-0.48516451	-0.48073927	-0.47554857	-0.46981459
13	-0.42185378	-0.41623399	-0.41243371	-0.40999296	-0.40745007
14	-0.35194013	-0.34786736	-0.34367342	-0.34043592	-0.33868515
15	-0.28010628	-0.27945628	-0.27802985	-0.27570824	-0.27298622
16	-0.20903185	-0.20942592	-0.21048456	-0.21161409	-0.21222230
17	-0.14772438	-0.14623186	-0.14541084	-0.14547299	-0.14644893
18	-0.10547459	-0.10399532	-0.10194063	-0.09949591	-0.09688174
19	-0.08395251	-0.08613283	-0.08797519	-0.08937865	-0.09026201
20	-0.07795531	-0.08254093	-0.08747783	-0.09271466	-0.09821423

NBAR=	15	16	17	18	19
SIGMA=	1.04156411	1.03947061	1.03756703	1.03583062	1.03424160
0	0.	0.	0.	0.	0.
1	-0.12602611	-0.12164612	-0.11841060	-0.11538487	-0.11256376
2	-0.24852953	-0.24684544	-0.24498917	-0.24336135	-0.24192284
3	-0.35908432	-0.35479557	-0.35090923	-0.34741175	-0.34424719
4	-0.45505246	-0.44843832	-0.44276212	-0.43758781	-0.43286221
5	-0.53238270	-0.52744384	-0.52269648	-0.51845331	-0.51463790
6	-0.58524414	-0.57796584	-0.57156709	-0.56577004	-0.56049721
7	-0.61542369	-0.60831400	-0.60197670	-0.59622147	-0.59098266
8	-0.62181443	-0.61641342	-0.61133241	-0.60678097	-0.60267658
9	-0.60466464	-0.59770282	-0.59165323	-0.58614945	-0.58112910
10	-0.57186131	-0.56680785	-0.56215146	-0.55793053	-0.55409361
11	-0.52415537	-0.52042184	-0.51698270	-0.51390626	-0.51113079
12	-0.46525834	-0.46055450	-0.45650226	-0.45279050	-0.44939133
13	-0.40421945	-0.40220477	-0.40018429	-0.39836005	-0.39670337
14	-0.33759380	-0.33611679	-0.33487025	-0.33376810	-0.33278024
15	-0.27074732	-0.26844269	-0.26643123	-0.26455965	-0.26283041
16	-0.21218469	-0.21295193	-0.21342056	-0.21384607	-0.21422497
17	-0.14783551	-0.14840164	-0.14914938	-0.14986748	-0.15054719
18	-0.09447641	-0.09248756	-0.09066039	-0.08901682	-0.08754398
19	-0.09077979	-0.09198183	-0.09292325	-0.09383402	-0.09471927
20	-0.10394893	-0.10989789	-0.11604463	-0.12237606	-0.12888159



DR=50

A= 2.05297384

NBAR= 6 7 8 9 10

SIGMA=

1.06233878 1.06082310 1.05819330 1.05521651 1.05222903

0	0.	0.	0.	0.	0.
1	-0.19091857	-0.18908859	-0.18643579	-0.18176361	-0.17985106
2	-0.37243599	-0.36888701	-0.36334723	-0.35536338	-0.34978131
3	-0.53557290	-0.53051961	-0.52200149	-0.51213298	-0.50208500
4	-0.67231038	-0.66605676	-0.65499946	-0.64365700	-0.63078634
5	-0.77626920	-0.76918668	-0.75657509	-0.74347375	-0.73006385
6	-0.84341873	-0.83591731	-0.82288654	-0.80824289	-0.79490777
7	-0.87260514	-0.86505980	-0.85246600	-0.83753069	-0.82366430
8	-0.86568422	-0.85854947	-0.84666824	-0.83294343	-0.81687570
9	-0.82715087	-0.82069548	-0.80969728	-0.79782811	-0.78520513
10	-0.76333066	-0.75776449	-0.74790797	-0.73758884	-0.72748637
11	-0.68135982	-0.67678617	-0.66853559	-0.65945607	-0.65128812
12	-0.58825413	-0.58467893	-0.57843601	-0.57099950	-0.56390362
13	-0.49031340	-0.48766975	-0.48343429	-0.47832862	-0.47274118
14	-0.39295507	-0.39113389	-0.38844833	-0.38565213	-0.38252769
15	-0.30088294	-0.29975969	-0.29801909	-0.29656921	-0.29550644
16	-0.21836629	-0.21781645	-0.21667085	-0.21556146	-0.21492039
17	-0.14938630	-0.14928840	-0.14877385	-0.14791853	-0.14693693
18	-0.09750423	-0.09773549	-0.09802727	-0.09810528	-0.09782114
19	-0.06547019	-0.06590197	-0.06693925	-0.06830467	-0.06978724
20	-0.05473824	-0.05523696	-0.05657953	-0.05855258	-0.06100190

NBAR= 11 12 13 14 15

SIGMA=

1.04937561 1.04671255 1.04425479 1.04199807 1.03992973

0	0.	0.	0.	0.	0.
1	-0.17459894	-0.17384400	-0.16868167	-0.16879215	-0.16487354
2	-0.34239670	-0.33722425	-0.33179452	-0.32662972	-0.32294568
3	-0.49401360	-0.48441205	-0.47830567	-0.47036140	-0.46461199
4	-0.62043688	-0.61004553	-0.60021924	-0.59296791	-0.58458334
5	-0.71678590	-0.70633343	-0.69507253	-0.68563552	-0.67764545
6	-0.78096109	-0.76866241	-0.75849541	-0.74755005	-0.73857704
7	-0.81099495	-0.79794477	-0.78708234	-0.77783958	-0.76823148
8	-0.80687603	-0.79566469	-0.78426493	-0.77494080	-0.76691234
9	-0.77323969	-0.76343393	-0.75423951	-0.74475553	-0.73678823
10	-0.71701503	-0.70737445	-0.69970894	-0.69278161	-0.68562875
11	-0.64361148	-0.63561851	-0.62808640	-0.62218142	-0.61717171
12	-0.55804546	-0.55286593	-0.54739963	-0.54176872	-0.53703374
13	-0.46756618	-0.46353084	-0.46043544	-0.45740551	-0.45406501
14	-0.37895357	-0.37534632	-0.37237573	-0.37039181	-0.36889376
15	-0.29444924	-0.29299096	-0.29103929	-0.28888177	-0.28706265
16	-0.21487640	-0.21526507	-0.21573822	-0.21592583	-0.21573870
17	-0.14609585	-0.14563372	-0.14569926	-0.14632725	-0.14721466
18	-0.09713301	-0.09608123	-0.09476542	-0.09331648	-0.09197029
19	-0.07123166	-0.07252260	-0.07357401	-0.07431794	-0.07483782
20	-0.06382284	-0.06694373	-0.07031438	-0.07389862	-0.07766978

NBAR= 16 17 18 19

SIGMA= 1.03803398 1.03629452 1.03469577 1.03322336

0	0.	0.	0.	0.
1	-0.16109986	-0.15813582	-0.15537958	-0.15281877
2	-0.31992696	-0.31696891	-0.31430940	-0.31190844
3	-0.45914146	-0.45416288	-0.44964487	-0.44553015
4	-0.57701771	-0.57033588	-0.56423299	-0.55864797
5	-0.67072262	-0.66424761	-0.65838775	-0.65306496
6	-0.73999985	-0.72231776	-0.71532234	-0.70893333
7	-0.75979908	-0.75219059	-0.74525315	-0.73891438
8	-0.75979246	-0.75318991	-0.74720841	-0.74176744
9	-0.72907994	-0.72222646	-0.71596935	-0.71024381
10	-0.67961785	-0.67409540	-0.66906339	-0.66446789
11	-0.61254515	-0.60829454	-0.60444648	-0.60094515
12	-0.53235874	-0.52823553	-0.52445393	-0.52098330
13	-0.45159897	-0.44923002	-0.44707680	-0.44511212
14	-0.36722073	-0.36575513	-0.36443755	-0.36324366
15	-0.28523632	-0.28362536	-0.28212877	-0.28074496
16	-0.21608261	-0.21625889	-0.21642582	-0.21657825
17	-0.14758791	-0.14807871	-0.14855368	-0.14900704
18	-0.09086164	-0.08983308	-0.08890131	-0.08806097
19	-0.07578849	-0.07657124	-0.07732951	-0.07806548
20	-0.08160767	-0.08569678	-0.08992477	-0.09428173

DB=55

A= 2.23620829

NBAR= 7 8 9 10 11

SIGMA=

1.05307519 1.05214956 1.05038384 1.04828368 1.04609776

0	0.	0.	0.	0.	0.
1	-0.24001662	-0.23836716	-0.23497200	-0.23215082	-0.22747331
2	-0.46684323	-0.46368528	-0.45747516	-0.45115835	-0.44358707
3	-0.66826712	-0.66385021	-0.65554161	-0.64562611	-0.63618223
4	-0.83397479	-0.82860921	-0.81867349	-0.80628350	-0.79448186
5	-0.95635950	-0.95037476	-0.93911863	-0.92573120	-0.91164806
6	-1.03114368	-1.02486689	-1.01279321	-0.99912893	-0.98439769
7	-1.05772741	-1.05147438	-1.03941213	-1.02561072	-1.01167302
8	-1.03916489	-1.03233349	-1.02202937	-1.00861536	-0.99550549
9	-0.98170032	-0.97635125	-0.96647509	-0.95449722	-0.94215731
10	-0.89387907	-0.88930617	-0.88082147	-0.87095461	-0.86033922
11	-0.78537296	-0.78167636	-0.77456869	-0.76661224	-0.75848628
12	-0.66577139	-0.66295006	-0.65736948	-0.65091360	-0.64474263
13	-0.54362360	-0.54159396	-0.53770419	-0.53287775	-0.52797399
14	-0.42593744	-0.42457054	-0.42222139	-0.41933427	-0.41604917
15	-0.31816407	-0.31732436	-0.31600827	-0.31469384	-0.31334516
16	-0.22450939	-0.22407892	-0.22328369	-0.22259014	-0.2220273
17	-0.14830354	-0.14818579	-0.14775272	-0.14716981	-0.14662511
18	-0.09218879	-0.09229819	-0.09236851	-0.09227344	-0.09195659
19	-0.05803510	-0.05828462	-0.05890584	-0.05972447	-0.06060803
20	-0.04667485	-0.04697166	-0.04783808	-0.04913680	-0.05077029

NBAR= 12 13 14 15 16

SIGMA=

1.04394838 1.04189378 1.03995894 1.03815146 1.03646994

0	0.	0.	0.	0.	0.
1	-0.22523406	-0.22049265	-0.21900300	-0.21513808	-0.21145288
2	-0.43716413	-0.43069786	-0.42455155	-0.41950815	-0.41507992
3	-0.62581710	-0.61761420	-0.60854300	-0.60108568	-0.59407770
4	-0.78257551	-0.77115218	-0.76156238	-0.75160273	-0.74248323
5	-0.89900903	-0.88608785	-0.87456849	-0.86430519	-0.85508407
6	-0.97043046	-0.95789542	-0.94521638	-0.93412186	-0.92365840
7	-0.99739573	-0.98455722	-0.97301556	-0.96161675	-0.95132725
8	-0.98272823	-0.96999848	-0.95880249	-0.94874917	-0.93961752
9	-0.93089472	-0.92014252	-0.90946885	-0.90002455	-0.89104922
10	-0.85005698	-0.84103998	-0.83269066	-0.82445470	-0.81719221
11	-0.75010140	-0.74206092	-0.73516665	-0.72902869	-0.72333946
12	-0.63890462	-0.63297330	-0.62706330	-0.62185071	-0.61682806
13	-0.52365037	-0.51993433	-0.51635629	-0.51269361	-0.50968853
14	-0.41269695	-0.40973828	-0.40743439	-0.40550336	-0.40355361
15	-0.31177948	-0.30994805	-0.30802392	-0.30634623	-0.30470309
16	-0.22209004	-0.22206632	-0.22190579	-0.22154400	-0.22154331
17	-0.14628720	-0.14626707	-0.14660081	-0.14710930	-0.14730642
18	-0.09142109	-0.09071522	-0.08991400	-0.08916264	-0.08854840
19	-0.06145695	-0.06219639	-0.06276797	-0.06321091	-0.06393018
20	-0.05267017	-0.05478773	-0.05708775	-0.05954416	-0.06213724

NBAR= 17 18 19

SIGMA=

1.03490847 1.03345919 1.03211342

	0.	0.	0.
0	0.	0.	0.
1	-0.20837338	-0.20551398	-0.20285964
2	-0.41087897	-0.40704554	-0.40354147
3	-0.58764392	-0.58175072	-0.57634367
4	-0.73424248	-0.72667068	-0.71970695
5	-0.84650535	-0.83865605	-0.83146246
6	-0.91413084	-0.90538859	-0.89735546
7	-0.94192236	-0.93328669	-0.92534969
8	-0.93115289	-0.92340395	-0.91629703
9	-0.88291171	-0.87543407	-0.86855527
10	-0.81049082	-0.80433923	-0.79868644
11	-0.71808914	-0.71328517	-0.70887900
12	-0.61230232	-0.60813338	-0.60429219
13	-0.50685227	-0.50425405	-0.50186948
14	-0.40176527	-0.40015457	-0.39868253
15	-0.30323281	-0.30186885	-0.30060736
16	-0.22146255	-0.22139834	-0.22134457
17	-0.14758679	-0.14786522	-0.14813706
18	-0.08797400	-0.08745103	-0.08697740
19	-0.06454665	-0.06514821	-0.06573474
20	-0.06485196	-0.06767631	-0.07060100

DB=60

A= 2.41941736

NBAR= 8 9 10 11 12

SIGMA=  
1.04570526 1.04521270 1.04405108 1.04257439 1.04097269

0	0.	0.	0.	0.	0.
1	-0.30687990	-0.30569273	-0.30294056	-0.29674886	-0.29543962
2	-0.59575239	-0.59339596	-0.58783127	-0.58040466	-0.57292444
3	-0.84997807	-0.84655374	-0.83841495	-0.82850195	-0.81727865
4	-1.05568366	-1.05142726	-1.04141523	-1.02919419	-1.01589635
5	-1.20306279	-1.19831140	-1.18728352	-1.17325668	-1.15878077
6	-1.28729846	-1.28239229	-1.27099194	-1.25638090	-1.24090774
7	-1.30884309	-1.30404621	-1.29272792	-1.27863152	-1.26316370
8	-1.27299048	-1.26848769	-1.25777373	-1.24458754	-1.23046951
9	-1.18889984	-1.18484177	-1.17532207	-1.16331458	-1.15084551
10	-1.06832661	-1.06485263	-1.05688819	-1.04667866	-1.03576225
11	-0.92425056	-0.92145871	-0.91504302	-0.90704408	-0.89823808
12	-0.76950517	-0.76740712	-0.76240096	-0.75633461	-0.74994938
13	-0.61552090	-0.61403800	-0.61041209	-0.60586659	-0.60124595
14	-0.47139321	-0.47040216	-0.46812191	-0.46511480	-0.46181575
15	-0.34351606	-0.34290167	-0.34167429	-0.34017104	-0.33844389
16	-0.23586323	-0.23553766	-0.23488618	-0.23425024	-0.23373267
17	-0.15070860	-0.15059891	-0.15022939	-0.14978867	-0.14942880
18	-0.08936235	-0.08939735	-0.08934595	-0.08916846	-0.08885894
19	-0.05255459	-0.05266773	-0.05300764	-0.05346813	-0.05396602
20	-0.04039544	-0.04053219	-0.04105989	-0.04189302	-0.04296890

NBAR= 13 14 15 16 17

SIGMA=  
1.03934908 1.03775908 1.03623155 1.03478023 1.03341030

0	0.	0.	0.	0.	0.
1	-0.29065786	-0.28777699	-0.28352327	-0.27945678	-0.27586909
2	-0.56522970	-0.55772760	-0.55101478	-0.54486103	-0.53904584
3	-0.80695678	-0.79614680	-0.78647710	-0.77732874	-0.76881404
4	-1.00250538	-0.99020472	-0.97788305	-0.96636942	-0.95573876
5	-1.14376673	-1.12957823	-1.11637788	-1.10415329	-1.09270199
6	-1.22582364	-1.21066885	-1.19669874	-1.18345364	-1.17117646
7	-1.24807100	-1.23375428	-1.21974686	-1.20675121	-1.19468291
8	-1.21599077	-1.20240769	-1.18972740	-1.17792493	-1.16688716
9	-1.13833343	-1.12586626	-1.11431879	-1.10332510	-1.09315978
10	-1.02525555	-1.01515110	-1.00526537	-0.99620581	-0.98775374
11	-0.88937384	-0.88117753	-0.87356504	-0.86641134	-0.85973720
12	-0.74334510	-0.73674627	-0.73065599	-0.72481463	-0.71943694
13	-0.59685498	-0.59255817	-0.58827656	-0.58450113	-0.58094244
14	-0.45864785	-0.45587130	-0.45337322	-0.45091859	-0.44866296
15	-0.33652785	-0.33455812	-0.33276478	-0.33103167	-0.32945049
16	-0.23327814	-0.23276764	-0.23216161	-0.23181109	-0.231444081
17	-0.14925124	-0.14929965	-0.14947544	-0.14947446	-0.14954126
18	-0.08844119	-0.08795892	-0.08750195	-0.08712795	-0.08677693
19	-0.05443702	-0.05483071	-0.05515963	-0.05567173	-0.05612686
20	-0.04424161	-0.04567730	-0.04725063	-0.04894225	-0.05073730

NBAR= 18 19  
SIGMA=  
1.03212194 1.03091270

0	0.	0.
1	-0.27252140	-0.26940258
2	-0.53366425	-0.52868892
3	-0.76092185	-0.75361347
4	-0.94587139	-0.93672366
5	-1.08209239	-1.07227239
6	-1.15978737	-1.14923276
7	-1.18348382	-1.17310417
8	-1.15665864	-1.14718796
9	-1.08372358	-1.07497406
10	-0.97991253	-0.97264650
11	-0.85355587	-0.84783390
12	-0.71444110	-0.70980683
13	-0.57764776	-0.57459959
14	-0.44658289	-0.44466396
15	-0.32797991	-0.32661612
16	-0.23110991	-0.23081208
17	-0.14962106	-0.14970934
18	-0.08645690	-0.08616667
19	-0.05657768	-0.05702214
20	-0.05262416	-0.05459357

DR=65

A= 2.60267633

NBAR= 9 10 11 12 13

SIGMA=  
1.03971924 1.03954232 1.03881332 1.03779113 1.03662488

0	0.	0.	0.	0.	0.
1	-0.40532029	-0.40448563	-0.40139018	-0.39753282	-0.39245208
2	-0.78493879	-0.78345021	-0.77764167	-0.76974124	-0.76074856
3	-1.11565712	-1.11370218	-1.10565031	-1.09424113	-1.08185515
4	-1.37884489	-1.37650457	-1.36665541	-1.35292722	-1.33742415
5	-1.56191355	-1.55924412	-1.54819481	-1.53307493	-1.51579395
6	-1.65925340	-1.65641587	-1.64494889	-1.62907960	-1.61142886
7	-1.67257466	-1.66981022	-1.65863425	-1.64297968	-1.62555031
8	-1.61040187	-1.60788669	-1.59747094	-1.58305113	-1.56664242
9	-1.48659221	-1.48437271	-1.47507495	-1.46233821	-1.44800255
10	-1.31818841	-1.31626753	-1.30842313	-1.29752754	-1.28548810
11	-1.12322533	-1.12165108	-1.11541659	-1.10668035	-1.09682119
12	-0.91893640	-0.91776381	-0.91302407	-0.90653465	-0.89913583
13	-0.72036822	-0.71956935	-0.71612556	-0.71146341	-0.70635921
14	-0.53925178	-0.53872061	-0.53644729	-0.53324804	-0.52972401
15	-0.38326388	-0.38291016	-0.38162399	-0.37980437	-0.37766498
16	-0.25609532	-0.25589184	-0.25523521	-0.25442967	-0.25357451
17	-0.15850113	-0.15843271	-0.15807840	-0.15764301	-0.15726078
18	-0.08984568	-0.08985761	-0.08973710	-0.08950290	-0.08918196
19	-0.04926669	-0.04929442	-0.04945046	-0.04967517	-0.04991867
20	-0.03595290	-0.03597587	-0.03627031	-0.03678529	-0.03748104

NBAR= 14 15 16 17 18

SIGMA=  
1.03540163 1.03417240 1.03296676 1.03180143 1.03068523

0	0.	0.	0.	0.	0.
1	-0.38818598	-0.38305383	-0.37604914	-0.37341981	-0.36904556
2	-0.75141966	-0.74243605	-0.73385636	-0.72564328	-0.71791019
3	-1.06859156	-1.05582225	-1.04345050	-1.03168952	-1.02060898
4	-1.32177548	-1.30590525	-1.29061468	-1.27613483	-1.26248468
5	-1.49812247	-1.48080197	-1.46418527	-1.44834147	-1.43341695
6	-1.59287213	-1.57476126	-1.55719517	-1.54052980	-1.52482328
7	-1.60770747	-1.58980471	-1.57261670	-1.55629642	-1.54091339
8	-1.54992723	-1.53352348	-1.51775256	-1.50272784	-1.48857492
9	-1.43298609	-1.41830453	-1.40403782	-1.39052211	-1.37778218
10	-1.27309410	-1.26066016	-1.24879794	-1.23751310	-1.22688001
11	-1.08685745	-1.07711099	-1.06770307	-1.05875428	-1.05033039
12	-0.89137722	-0.88381328	-0.87644084	-0.86947752	-0.86291563
13	-0.70107237	-0.69572836	-0.69072961	-0.68595636	-0.68146782
14	-0.52626103	-0.52293065	-0.51965563	-0.51656795	-0.51367192
15	-0.37539540	-0.37320578	-0.37107055	-0.36906985	-0.36718874
16	-0.25266169	-0.25169368	-0.25090433	-0.25013329	-0.24942128
17	-0.15700315	-0.15683553	-0.15657578	-0.15637717	-0.15620624
18	-0.08880932	-0.08844633	-0.08813564	-0.08784316	-0.08757461
19	-0.05013992	-0.05033714	-0.05066092	-0.05096005	-0.05126489
20	-0.03832683	-0.03929884	-0.04037863	-0.04155163	-0.04280625

NBAR= 19

SIGMA=  
1.02962214

0 0.  
1 -0.36493282  
2 -0.71066475  
3 -1.01021987  
4 -1.24967998  
5 -1.41942668  
6 -1.51009203  
7 -1.52648510  
8 -1.47530681  
9 -1.36583175  
10 -1.21691008  
11 -1.04243684  
12 -0.85676256  
13 -0.67726638  
14 -0.51096678  
15 -0.36542957  
16 -0.24876517  
17 -0.15605977  
18 -0.08732973  
19 -0.05157228  
20 -0.04413339



DE=70

A= 2.78591025

NBAR= 11 12 13 14 15

SIGMA=

1.03482272 1.03440964 1.03372557 1.03288995 1.03197660

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1	-0.56311377	-0.56009278	-0.55492219	-0.54917761	-0.54248814
2	-1.08846802	-1.08259762	-1.07296306	-1.06133720	-1.04898718
3	-1.54212744	-1.53384796	-1.52040577	-1.50399689	-1.48656437
4	-1.89722682	-1.88717672	-1.87066118	-1.85096464	-1.82958099
5	-2.13638669	-2.12524375	-2.10690469	-2.08491012	-2.06137550
6	-2.25312152	-2.24155578	-2.22268117	-2.19980308	-2.17536277
7	-2.25191051	-2.24060097	-2.22210202	-2.19992703	-2.17596236
8	-2.14682476	-2.13635382	-2.11912137	-2.09849453	-2.07641879
9	-1.95910775	-1.94985432	-1.93471991	-1.91640222	-1.89682592
10	-1.71422003	-1.70641115	-1.69369797	-1.67843677	-1.66195016
11	-1.43865228	-1.43241242	-1.42215665	-1.40993239	-1.39687780
12	-1.15691020	-1.15219563	-1.14445449	-1.13508216	-1.12508556
13	-0.88933043	-0.88593917	-0.88046978	-0.87389962	-0.86678613
14	-0.65096860	-0.64868478	-0.64496458	-0.64059233	-0.63596597
15	-0.45111140	-0.44973939	-0.44744848	-0.44466214	-0.44170889
16	-0.29321308	-0.29248184	-0.29133343	-0.28994763	-0.28842848
17	-0.17592680	-0.17554583	-0.17498055	-0.17438440	-0.17380476
18	-0.09558040	-0.09541662	-0.09510782	-0.09471341	-0.09429615
19	-0.04881389	-0.04885228	-0.04891206	-0.04909676	-0.04902161
20	-0.03355573	-0.03369138	-0.03398596	-0.03441713	-0.03496580

NBAR= 16 17 18 19

SIGMA=

1.03103155 1.03008354 1.02915037 1.02824280

0	0.	0.	0.	0.
1	-0.53565500	-0.52901473	-0.52259642	-0.51646336
2	-1.03650177	-1.02417982	-1.01228583	-1.00093663
3	-1.46883066	-1.45138164	-1.43453498	-1.41845557
4	-1.80787565	-1.78655563	-1.76596709	-1.74631259
5	-2.03753674	-2.01405099	-1.99137807	-1.96974008
6	-2.15048862	-2.12603748	-2.10242879	-2.07989329
7	-2.15167490	-2.12780321	-2.10474885	-2.08274305
8	-2.05404168	-2.03200716	-2.01073637	-1.99044207
9	-1.87689003	-1.85731061	-1.83840832	-1.82036739
10	-1.64529817	-1.62891594	-1.61310481	-1.59801857
11	-1.38362890	-1.37059760	-1.35802793	-1.34603971
12	-1.11489858	-1.10491400	-1.09528176	-1.08609474
13	-0.85966976	-0.85266391	-0.84591412	-0.83948369
14	-0.63124081	-0.62361713	-0.616216985	-0.611793909
15	-0.43870593	-0.43577935	-0.43296468	-0.43028832
16	-0.28698319	-0.28555576	-0.28419415	-0.28290856
17	-0.17316171	-0.17256528	-0.17200521	-0.17148459
18	-0.09390172	-0.09352009	-0.09316018	-0.09282455
19	-0.04910095	-0.04929664	-0.04944642	-0.04960710
20	-0.03561599	-0.03635444	-0.03717022	-0.03805423

DB=75

A= 2.96914416

NBAR= 12 13 14 15 16

SIGMA=

1.03083444 1.03065580 1.03022753 1.02964683 1.02897666

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1	-0.85819915	-0.85532967	-0.84854360	-0.83925460	-0.82871000
2	-1.65578571	-1.65022409	-1.63698515	-1.61938676	-1.59951920
3	-2.33843318	-2.33060092	-2.31199095	-2.28724059	-2.25923064
4	-2.86392674	-2.85443038	-2.83190894	-2.80175421	-2.76764685
5	-3.20632511	-3.19581300	-3.17081517	-3.13751116	-3.09988371
6	-3.35768601	-3.34680411	-3.32094076	-3.28648853	-3.24749261
7	-3.32765123	-3.31703726	-3.29187989	-3.25824967	-3.22024497
8	-3.14110455	-3.13129374	-3.10790359	-3.07693630	-3.04185525
9	-2.83386925	-2.82521829	-2.80464360	-2.77723986	-2.74622104
10	-2.44732529	-2.44004595	-2.42281920	-2.39980021	-2.37382677
11	-2.02326471	-2.01744998	-2.00366402	-1.98532974	-1.96461305
12	-1.59942556	-1.59501867	-1.58451647	-1.57054325	-1.55473032
13	-1.20593059	-1.20275520	-1.19526458	-1.18525386	-1.17400613
14	-0.86351194	-0.86136345	-0.85631123	-0.84962687	-0.84206423
15	-0.58356746	-0.58223630	-0.57903577	-0.57478820	-0.56999135
16	-0.36879532	-0.36804244	-0.36627521	-0.36390704	-0.36129348
17	-0.21445232	-0.21405473	-0.21317154	-0.21203904	-0.21073309
18	-0.11184821	-0.11167096	-0.11121665	-0.11061240	-0.10995016
19	-0.05323831	-0.05320909	-0.05312766	-0.05301271	-0.05293698
20	-0.03424989	-0.03427829	-0.03440760	-0.03463502	-0.03495421

NBAR= 17 18 19

SIGMA=

1.02825822 1.02751865 1.02677573

0	0.	0.	0.
1	-0.81770855	-0.80664230	-0.79578144
2	-1.57866870	-1.55770457	-1.53713988
3	-2.22986820	-2.20034397	-2.17137986
4	-2.73191667	-2.69598776	-2.66073859
5	-3.06042230	-3.02074647	-2.98182609
6	-3.20663220	-3.16554893	-3.12524605
7	-3.18042096	-3.14038134	-3.10110435
8	-3.00507739	-2.96810663	-2.93184542
9	-2.71373704	-2.68108383	-2.64905772
10	-2.34661231	-2.31926185	-2.29244214
11	-1.94291127	-1.92110880	-1.89973579
12	-1.53819159	-1.52157882	-1.50529611
13	-1.16222577	-1.15040155	-1.13882022
14	-0.83416395	-0.82624207	-0.81848976
15	-0.56499127	-0.55998065	-0.55508089
16	-0.35855081	-0.35582805	-0.35316614
17	-0.20939259	-0.20806094	-0.20676956
18	-0.10926450	-0.10850487	-0.10792729
19	-0.05286037	-0.05279923	-0.05275464
20	-0.03535749	-0.03583709	-0.03638556

DB=80

A= 3.15237805

NBAR= 13 14 15 16 17

SIGMA=

1.02742040 1.02741805 1.02718595 1.02680436 1.02632730

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1	-1.58502102	-1.58480850	-1.57258637	-1.55279876	-1.52873235
2	-3.05208236	-3.05185124	-3.02840322	-2.99060532	-2.94457034
3	-4.29688382	-4.29658681	-4.26367486	-4.21057725	-4.14592624
4	-5.23967397	-5.23922759	-5.19927573	-5.13479346	-5.05629462
5	-5.83308757	-5.83262670	-5.78844464	-5.71719593	-5.63043752
6	-6.06605726	-6.06562161	-6.02001983	-5.94643998	-5.85686624
7	-5.96216673	-5.96168942	-5.91729326	-5.84567207	-5.75848538
8	-5.57349145	-5.57305375	-5.53204054	-5.46590602	-5.38539332
9	-4.97193587	-4.97159248	-4.93548083	-4.87722004	-4.80631590
10	-4.23859578	-4.23827350	-4.20798308	-4.15914720	-4.09971118
11	-3.45286638	-3.45259959	-3.42839915	-3.38939112	-3.34192339
12	-2.68402240	-2.68385604	-2.6544106	-2.63574061	-2.59961790
13	-1.98545486	-1.98531554	-1.97206627	-1.95073411	-1.92478499
14	-1.39138004	-1.39126782	-1.38228972	-1.36782627	-1.35024725
15	-0.91741628	-0.91737556	-0.91166112	-0.90245345	-0.89127194
16	-0.56365303	-0.56362231	-0.56031031	-0.55500164	-0.54855212
17	-0.31755384	-0.31751583	-0.31578417	-0.31299214	-0.30961602
18	-0.15923030	-0.15923452	-0.15839060	-0.15704033	-0.15540659
19	-0.07076067	-0.07078616	-0.07050167	-0.07006905	-0.06954918
20	-0.04236177	-0.04234225	-0.04230141	-0.04228378	-0.04231567

NBAR= 18 19

SIGMA=

1.02579151 1.02522214

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1	-1.50252389	-1.47558002
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3	-4.07552856	-4.00316447
4	-4.97081822	-4.88205424
5	-5.53597617	-5.43887913
6	-5.75933790	-5.65909136
7	-5.66356039	-5.56599379
8	-5.29774248	-5.20765736
9	-4.72913050	-4.64980793
10	-4.03501803	-3.96854159
11	-3.29026699	-3.23719537
12	-2.56031400	-2.51993972
13	-1.89656071	-1.86757765
14	-1.33113574	-1.31151886
15	-0.87912116	-0.86665486
16	-0.54155239	-0.53437945
17	-0.30895797	-0.30221583
18	-0.15363916	-0.15183376
19	-0.06899779	-0.06844609
20	-0.04241052	-0.04257395

## *MISSION of Rome Air Development Center*

*RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C<sup>3</sup>) activities, and in the C<sup>3</sup> areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.*

